IMPROVING ACCESS TO DRINKING WATER IN THE DEVELOPING WORLD THROUGH GUIDED HOUSEHOLD WATER TREATMENT AND STORAGE TECHNOLOGY SELECTION

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IMPROVING ACCESS TO DRINKING WATER IN THE DEVELOPING WORLD THROUGH GUIDED HOUSEHOLD WATER TREATMENT AND STORAGE TECHNOLOGY

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To every person in the world who has ever lived without a clean and safe source of water.

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I wish to thank my advisor and my committee for their guidance throughout this research, and my research group who offered endless advice and support.

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LIST OF SYMBOLS AND ABBREVIATIONS

AfDF	African Development Fund of the African Development Bank
AsDF	Asian Development Fund of the African Development Bank
CRS	Creditor Reporting System
DAC	Development Assistance Committee
DALY	Disability Adjusted Life Year
DHF	Dengue Hemorrhagic Fever
EC	European Commission
GBD	Global Burden of Disease
GDP	Gross Domestic Product
GLAAS	Global Annual Assessment of Sanitation and Drinking Water
HIPC	Highly Indebted Poor Countries
HWTS	Household Water Treatment and Storage
IDA	International Development Association of the World Bank
IDB	Inter-American Development Bank
JE	Japanese Encephalitis
JMP	Joint Monitoring Programme for Water Supply and Sanitation
LA&C	Latin America and the Caribbean
LDC	Least Develop Country
LF	Lymphatic Filariasis
LMIC	Lower Middle Income Country
MDG	Millennium Development Goal

NGO	Non-governmental Organization
ODA	Official Development Assistance
OECD	Organisation for Economic Co-operation and Development
OLIC	Other (non-LDC) Low Income Country
PHAST	Participatory Hygiene And Sanitation Transformation
POU	Point-of-Use
UK	United Kingdom
UMIC	Upper Middle Income Country
UN	United Nations
US	United States
WHO	World Health Organization
WQT	Water Quality Target
WSP	Water Safety Plan
WSS	Water Supply and Sanitation
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
YLD	Years of Life lost due to Disability
YLL	Years of Life Lost

SUMMARY

Beginning at least as early as 1977, the international community formally recognized that drinking water and sanitation were not a reality for large percentage of the world and that it was necessary to take action to change this. Over the following three decades more actions and agreements were made, each with a progressively acute awareness of the requirements to achieve this goal and the failures of previous attempts. Poor information sharing and underestimation of cost were identified as two of the greatest recurring impediments. The Millennium Declaration made in 2000 is the newest campaign to move towards this goal, among others, and provides a metric against which progress and success can be measured.

At this point, great success has been made overall towards the Millennium Development Goals. Millions of people have gained access to improved sources of drinking water and several regions have surpassed their goals. Unfortunately this progress is not homogenous and the definitions of success are misleading. Sub-Saharan Africa is lagging significantly behind due to water scarcity, large population growth, urban versus rural disparities, and slow growth of piped infrastructure. Limitations to the sector as a whole have been identified as logistics, funding limitations, inadequate cost recovery, and inadequate operations and maintenance. Additionally, the metric of access to an "improved" source does not equate to safe drinking water and is not attached to sanitation improvements or overall health improvements.

In further examining the financial aspects of achieving the goals, it is clear that there is a great deal of inconsistency. Many donors, whether public or private,

international or local, are giving money to the development goals. But the money given is often not equivalent to the original commitment, not given to the countries with the greatest need, not given to the water and sanitation sector specifically, given in the form of loans which must be repaid, given to new large scale systems which are not always appropriate, or not sufficient to achieve the desired target. This makes it very difficult to achieve and sustain progress in the areas which have been difficult to reach thus far, including Sub-Saharan Africa.

The need for progress toward safe water is clear from the perspective of health. Water is needed for hygienic practices, as well as consumption, and it is counterproductive to use water that is not clean. One of the leading causes of both death and disability worldwide is diarrheal disease which can largely be attributed to unsafe water. Studies have shown that there is a positive correlation between drinking water interventions and improved health outcomes, especially with increased proximity of the source, and for this reason there is an even greater need to tie the definition of success in improved water to overall health outcomes. It is also important that public health practitioners, engineers, and professionals from other related sectors work together to improve knowledge sharing and ultimately efficiency in achieving the goal of safe water for all.

Point-of-use interventions are among the best approaches to delivering means of water treatment to unreached communities because they can be deployed much more quickly and easily than a traditional piped system, require less expertise, and reduce recontamination that may occur during transport and storage. Such technologies utilize a variety of mechanisms to address a range of contaminants and concerns. In order for any technology to be successful though, it must be accompanied by a method of safe storage as well as education, training, and continued external support.

This information is synthesized in a technology selection guide, which attempts provide assistance in technology selection by addressing the immediate issue of water quality for the sake of health benefits, while also considering the context of the installation, the user preferences, the level of expertise of the implementers, the cost, operations and maintenance requirements, and common areas of failure. Simultaneously it allows for technologies to be compared so that the most appropriate technology may be chosen. The guide is marketed towards a non-technical audience with the intention of promoting knowledge sharing and serving as a translation between the developers of the treatment technology and those who implement it in developing countries.

CHAPTER 1

INTRODUCTION

Today, the statistics for global drinking water and sanitation access mark the opening statements of nearly every report and publication from the sector; 1 billion without water and 2.5 billion without sanitation. These statistics have been so often used that they have almost become irrelevant, and the urgency they should provide has faded. Like the statistics, the importance of clean water and sanitation for healthy life is well known. Yet the effect is lacking. In this modern era, safe water and sanitation are still not a reality for many. This is not for a lack of effort though; billions of dollars and decades of commitment have made significant progress. In several areas of the world access has improved drastically, increasing the global average, and making the problem, for many, much improved. But, despite all of this - the knowledge and technology of our age - this most basic of needs is still not secured for everyone.

In order to fully understand the state of global drinking water and sanitation, and how it can be improved, many questions must be addressed. Which areas of the world have water and which do not? In many areas of the world progress is being made while in others the numbers are not changing. What is it about those making progress that is allowing them to do so and what is lacking in the remainder? What has been tried in the past and why has it failed? Who is supporting this effort? Where can the most effect be made?

The first part of this document attempts to answer these questions. In the first chapter, historical actions are explored. Through the wording of the commitments made in international agreements the evolution of our understanding of the problem and the reason for failure of previous commitments becomes evident. From this it is clear not only how many decades the international community has tried unsuccessfully to solve this problem, but also how we can learn from mistakes.

In the second chapter the current status of global drinking water access is discussed. This section attempts to answer the questions of which populations do and do not have water, and why. Climate factors, population growth, means of access, and the access of urban versus rural dwellers are addressed. The metric of an "improved source" is defined and the limitations of this metric are highlighted. The major limitations to the spread of access demonstrate the areas of focus for future efforts. Finally, suggestions are made for addressing these limitations and redefining successful progress.

The third chapter addresses financial support for drinking water interventions. Major donors and recipients are identified, as well as the form and pathway of giving, be it loans or grants, bilateral or multilateral. Donors often have a means of deciding the distribution of their support, yet this is not always consistent or based upon greatest need. These preferences are analyzed as well as to what extent disbursed funds match the original commitments. The adequacy of funds to support the efforts of developing countries is also discussed. Finally, the controversy over the participation of the private sector in providing drinking water is introduced.

The fourth chapter covers the role of clean drinking water in healthy life. In this section the basic water requirements for consumption, hygiene, and amenity use are discussed. Scientific evidence of the ability of drinking water interventions to improve health is presented. The magnitude of the effect of water related diseases on global health, especially that of children is revealed. This chapter concludes with the role of water quality regulations and intersectoral collaboration.

The fifth and final chapter of the literature review discusses technologies used for drinking water treatment in the developing world. One of the greatest debates in this area is whether to treat water at the source or the point of use. Support for point of use technologies is given here as well as for the consideration of turbidity and a means of safe storage in any technology intervention. Finally, the chapter discusses the need for financing, education, training, and long term assistance to ensure the sustainability of the technology.

The second part of the document describes how this information is synthesized to present new solutions. Among the conclusions of the literature review are the need for greater intersectoral collaboration, better understanding of financing and cost recovery, and the necessity of consideration for operations and maintenance. The remaining chapters of the document describe the basis for and format of a technology selection guide which will address these topics. The technology selection guide itself can be found in Appendix A of the document.

There are many factors which contribute to the status of water access in any given location. Progress towards universal access thus far has shown that these factors are easier to overcome in some areas than in others. In order to overcome these factors in the most challenging situations the lessons learned from the failures of the past thirty years must be built upon and new approaches must be made using collaborations of the expertise of everyone interested in changing this problem.

PART 1

LITERATURE REVIEW

CHAPTER 2

HISTORY OF DIPLOMATIC ACTIONS CONCERNING WATER

For more than thirty years the international diplomatic community has recognized the need to greatly improve water and sanitation standards for health and economic development in the world's poorest nations. Yet the lack of clean water and adequate sanitation remains one of the world's foremost challenges. The following history demonstrates what actions have been taken by the global community in prior decades, and where these have fallen short of proposed deadlines and desired outcomes.

Focus of rural water supply and sanitation began in many areas of the world during the post-colonial era as post-colonial sates struggled to extend 'modern' infrastructure to their rapidly expanding populations [1]. The more recent string of initiatives began in 1977. The United Nations Conference on Water in Mar del Plata, Argentina laid the groundwork for the coming decades. This conference produced the Mar del Plata Action Plan in which it was recognized that, *"relatively little importance has been attached to water resources systematic measurement. The processing and compilation of data have also been seriously neglected"* [2]. The Mar del Plata conference also declared the upcoming decade (1981-1990) to be the International Drinking Water Supply and Sanitation Decade with the target of "community and water supply sanitation to include all rural and urban areas" [3].

The Alma-Ata Declaration on Primary Health Care of 1978 was the first to connect water and health. It made a clear statement when it called *"all governments, all health and development workers, and the world community to promote the health of all* *the people of the world".* More importantly, it did so with a specific call for *"an adequate supply of safe water and basic sanitation*" [4].

During the International Drinking Water Supply and Sanitation Decade of the 1980s came the realization that if the world were to achieve the ambitious goal of 'water and sanitation for all', "a radical overhaul of precepts and investment strategies governing the proliferation of taps, pumps, and pipes in the developing world" was needed [5]. The majority of the global population without access to water and sanitation was poor and governments and donors had to be persuaded to invest in low-cost technologies which could be extended to low-income urban and rural areas. So began the focus on small community managed systems [1].

The decade also saw an eruption of donor investments in the sector. At the decade's end, more than US$73 million had been spent on water and sanitation, but this was largely tied up in projects and programs and unavailable to communities [1]. The decade did not see the accomplishment of global access to water and sanitation, but important lessons were learned about the resources and strategy that would be needed to do so:

> *"Despite the failure to meet the quantitative goals, much was learnt from the experience of the water and sanitation decade... There was further realisation of the importance of comprehensive and balance country-specific approaches to the water and sanitation problem. Most importantly, perhaps, was the realisation that the achievement of this goal that was set at the beginning of the decade would take far more time and cost far more money than was originally thought."* [6]

Additionally, it became clear that many of the systems constructed during the decade were inoperable shortly after implementation as a result of poor maintenance and management, introducing the concern for 'appropriate technology' and the sustainability thereof [1].

In 1990, the Global Consultation on Safe Water and Sanitation for the 1990's met in New Delhi, India and produced the New Delhi Statement. In this statement it was concluded that *"Safe water and proper means of waste disposal ... must be at the center of integrated water resources management"*[7]. Just two weeks later, the World Summit for Children met in New York and agreed to promote clean water and sanitation for all the world's children [8].

At the UN Conference on Environment and Development (UNCED Earth Summit) in Rio de Janeiro in 1992 world leaders once again committed themselves to a comprehensive program to supply water and sanitation to the hundreds of millions of people who lacked them around the world. The conference produced Agenda 21, a strategy for sustainable development in the 21st century which stated, *"The holistic management of freshwater...and the integration of sectoral water plans and programmes within the framework of national economic and social policy, are of paramount importance for action in the 1990s and beyond,"* [9].

Also that year, the International Conference on Water and the Environment held in Dublin, Ireland produced the Dublin Statement on Water and Sustainable Development. This document was based on four guiding principles, among which were:

> *Principle 2: Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels*
>
> *Principle 3: Women play a central part in the provision, management and safeguarding of water*
>
> *Principle 4: Water has an economic value in all its competing uses and should be recognized as an economic good [10]*

Throughout the remaining years of the 1990's the global community produced several other documents recognizing the priority of water and sanitation for the development of nations and the quality of life for their people. Among these were the Programme of Action produced by the UN International Conference on Population and Development in Cairo (1994), the Action Plan produced by the Ministerial Conference on Drinking Water Supply and Environmental Sanitation in Noordwijk (1994), the Beijing Declaration and Platform for Action (1995), the Copenhagen Declaration on Social Development (1995), the Rome Declaration on Global Food Security (1996), the Habitat Agenda produced by UN Conference on Human Settlements in Istanbul (1996), and the Marrakech Declaration produced after the First World Water Forum (1997) [11].

At the UN General Assembly in March 2000, the world's leaders recommitted themselves once again to facing the world's most daunting problems with the Millennium Development Goals established in the UN Millennium Declaration. Target 7c of that declaration is to reduce by half the proportion of people without sustainable access to safe drinking water and basic sanitation. Additionally, the assembly resolved to "*support the consolidation of democracy in Africa and assist Africans in their struggle for lasting peace, poverty eradication and sustainable development, thereby bringing Africa into the mainstream of the world economy"* [12].

Later in 2000, the Second World Water Forum met in The Hague, Netherlands. Among the resolutions of the forum were:

- Involve all stakeholders in integrated management
-Move to full-cost pricing of water services
-Increase public funding for research and innovation
-Massively increase investments in water [13]

In 2001, the Ministerial Declaration of the International Conference on Freshwater in Bonn, Germany concluded that *"Combating poverty is the main challenge for achieving equitable and sustainable development, and water plays a vital role in relation to human health, livelihood, economic growth as well as sustaining ecosystems"* [14]. In 2002, the World Summit on Sustainable Development, Rio+10, met in Johannesburg and produced the Plan of Implementation in which it was resolved to:

> *"Halve, by the year 2015... the proportion of people who do not have access to basic sanitation, which would include actions at all levels to:*
> *- Develop and implement efficient household sanitation systems;*
> *- Improve sanitation in public institutions, especially schools;*
> *- Promote safe hygiene practices;*
> *- Promote education and outreach focused on children, as agents of behavioural change;*
> *- Promote affordable and socially and culturally acceptable technologies and practices;*
> *- Develop innovative financing and partnership mechanisms;*
> *- Integrate sanitation into water resources management strategies"*[15]

Moreover, the Third and Fourth World Water Forums, in Japan (2003) and Mexico (2006) respectively, as well as the United Nations World Water Development Reports reaffirmed the importance of water and sanitation interventions throughout the developing world and the financial commitments needed by donor countries to realize these interventions [11].

The statements drawn from the proceedings of the conferences listed previously decisively illustrate a pattern of recognition of the vitality of water and sanitation interventions and an inability to complete these commitments. One reason for this seems to be a chronic lack of information and underestimation of costing or failure to integrate financial planning and investment. The UN has declared the decade of 2005-2015 to be the *International Decade for Action: Water for Life*, but in order for the resolution to be more successful than the others, the shortcomings of a defined scope, financing, and sectoral collaboration must be corrected.

CHAPTER 3

STATUS OF GLOBAL WATER

3.1 Global Overview

According to the UN 2010 Millennium Development Goals Report [16], as of 2008 approximately 87% of the world and 84% of the developing world had access to an improved source of drinking water. Several regions of the world have already met or exceeded their Millennium Development Goal (MDG) targets, including Southern Asia, Eastern Asia, Southeastern Asia, and Northern Africa, and many others are on track to meet their goals on time. At the current rate, the world as a whole is projected to meet or exceed the MDG target by 2015. By this time, 86% of the developing world will have acquired access to an improved drinking water source [16].

Additionally, great improvements have been made in urban-rural disparities. In all regions, increased access was largely experienced by the rural population. In developing countries, urban drinking water access has remained relatively unchanged at 94% since 1990. During this same period, rural access has increased from 60% to 70% [16].

While these numbers are optimistic, they can be misleading. The greatest concern with such progress is the metric by which it is defined. The United Nations uses the qualification of "improved" sources to measure levels of access. But this term is deceptive and does not require the water quality it implies. While significant gains are being made in access to improved sources, the water in many areas still may not be safe to consume. This is discussed further below.

In terms of these improved sources, thus far the greatest progress has been made in Eastern Asia where coverage grew 30% between 1990 and 2008 so that now more than 89% of the population has access to an improved drinking water source. By comparison, Sub-Saharan Africa increased access by 11%, so that only 60% of the population is currently served [16]. With a growth rate just above average for the nine regions being monitored, Sub-Saharan Africa still has the second smallest access percentage. While moderate gains have been made in terms of percentage points, in real population numbers more than 884 million people worldwide currently do not have access to improved drinking water sources and, after 35 years of directed effort and exposure, 672 million still will not in 2015 based on current progress [17].

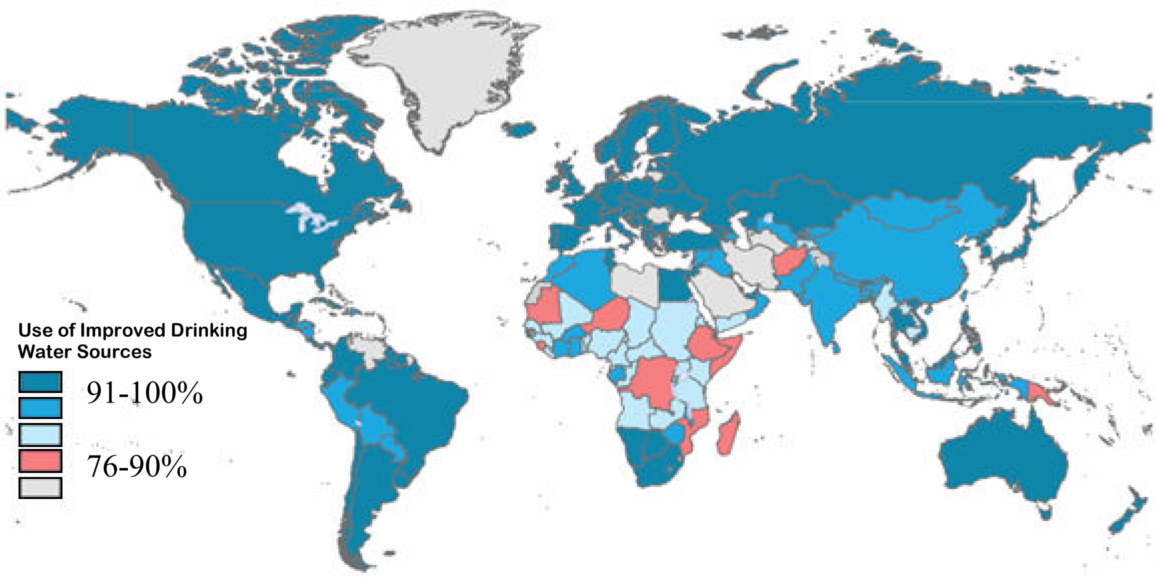

Figure 3.1 Improved Drinking Water Global Coverage, 2008 [17]

Additionally, global progress is based on the average progress of all regions, meaning that where one region may have experienced significant gains in improved drinking water access (i.e. Eastern Asia), another has experienced insufficient improvement or even decreased access. Such is the case with Sub-Saharan Africa with only 60% access and Oceania experiencing a one percent decrease in access since 1990. In fact, 37% of the global population who do not have access to improved drinking water sources live in Sub-Saharan Africa, making up the largest regional percentage of those without access, and leading the next lacking region by more than 12%. At the current rates of progress in Africa, the region will not meet the MDG water target until 2035 [18]. Figure 3.1 shows the lack of access in Africa compared to other regions worldwide. Together, China and India make up nearly one half of the population being monitored for drinking water improvement. With their significant improvements weighted heavily by large populations, these two countries skew global analysis [17].

3.2 Defining Improved Access

The definition of "improved" access and setting a global quality standard has also proved to be one of the greatest challenges in collecting and producing a coherent picture of the world's drinking water access. The term "improved" was first used by the JMP in the 2000 Global Water Supply and Sanitation Assessment [19] to better classify water and sanitation facilities during assessment. According to the JMP definition, an improved water supply is defined as one that, *"by nature of its construction or through active intervention, is protected from outside contamination, in particular from contamination with faecal matter"* and generally includes piped water into dwelling, piped water to yard/plot, public taps or standpipes, tubewells or boreholes, protected dug wells, protected springs, and rainwater (see Table 3.1) [20]. It is important to note that this definition does not include any requirements for the final water quality.

Table 3.1 Drinking Water Technologies Considered Improved and Unimproved [20]

Improved	Unimproved
Household Connection	Unprotected Well
Public Standpipe	Unprotected Spring
Borehole	Vendor-provided Water
Protected Dug Well	Bottled Water*
Protected Spring	Tanker Truck-provided Water
Rainwater	
*Not considered "improved' because of limitations concerning the potential quantity of supplied water, not the quality.	

There are often several different institutions within a country responsible for collecting data, each with their own monitoring definitions and methods, and additionally, there may be differences between the definitions used at the national and MDG levels. For example, in many African countries, "without access" may mean that the population is without access to any facility, while in Latin America and the Caribbean, it is more likely the case that those "without access" have access to a facility but it may be considered unsatisfactory by the local or national monitoring agencies [19]. For this reason, several different, and at times widely varying, estimates of improved drinking water access may be reached. Also, World Health Organization (WHO) Drinking Water Quality Guidelines sets specific measures for microbial contamination and chemical hazard indicators, but allows countries to adapt these to their own socioeconomic context, there again causing estimates of "safe" water to vary [17]. Current guidelines often require expenditures which are unrealistic in many resource-poor developing countries, forcing them to choose which standards to meet [21].

3.3 Regional Hurdles in Africa

3.3.1. Water Scarcity

In order to expand improved water access, there must first be reliable water resources which can be developed. Already, the world's population can only use a small percentage of the water on Earth, and fresh water resources are not distributed evenly. Figure 3.2 below shows the number of dry months per year across the globe. It is interesting to note that the majority of wealthy areas in the world also experience frequent rainfall which allows rivers, reservoirs and aquifers to be refilled regularly, allowing those countries to store and transfer water. In large parts of Africa this is not the case, and ground water resources are the only option for drinking water, especially through dry seasons. These resources are only beneficial though if they are available at the point of need and are properly managed and treated so that over abstraction and contamination do not occur [22].

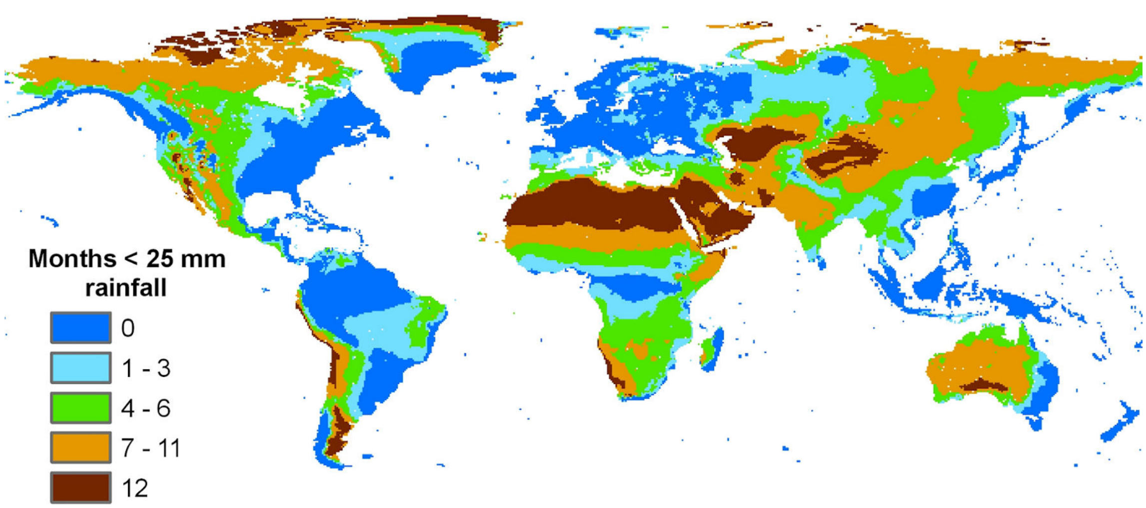

Figure 3.2 Global Distribution of Rainfall: The Number of Dry Months per Year [22]

3.3.2 Population Growth

One cause of the modest percentage growth for improved water coverage globally is the large simultaneous global population growth. Between 1990 and 2000, it is estimated that the human population grew by 15% from 5.27 to 6.06 billion inhabitants. Although growth in coverage was small, 620 million people must have obtained access just for the percentage of access to be maintained. Despite the population increase of 789 million during these ten years, coverage was extended to 816 million people (224,000 people per day). Thus while the world population grew, the global access percentage also rose, and coverage was extended not only to the world's new population but further into the backlog as well [19].

Compared to other regions of the world, Africa experienced exceptional growth. Table 3.2 shows that Africa's growth rate was nearly double the global average between 1990 and 2000. In Africa specifically, approximately 82 million people gained access to a piped connection during the 1990s while use of other forms of access decreased by 5%, as did the percentage without any access. The population growth during this time was 169 million, meaning effectively that only 49% of the new population, and none of the existing population acquired a piped connection. During this time 83% of Asia's new population and 100% of the new Latin America and Caribbean population had access to a piped connection. Compared to 49% in Asia, 66% in Latin America and the Caribbean, and the global average of 47%, Africa with 24% has the lowest access to this type of service by more than half [19].

Table 3.2 World Population by Region (in Millions) [23]

	Africa	Asia	LA&C	Oceania	Europe	N. America	Global
1990	615	3180	441	26	722	282	5266
2000	784	3683	519	30	729	310	6055
% Increase	27.5	15.8	17.8	15.4	1	9.9	15.0

3.3.3 Means of Access

In many parts of the world, investment in piped water connections drives the increase in improved access coverage. Worldwide the number of people who gained access to piped connections was double the number who gained access due to other means. In Eastern Asia, Latin America and the Caribbean, and Northern Africa, increases in access were exclusively due to installation of piped connections. In Sub-Saharan Africa the opposite was true. Improved access growth by other means was 3.5 times higher than that of piped access. The disparity between rural and urban populations also played a role. Worldwide only 31% of rural inhabitants enjoyed access to a piped connection while 73% of the urban population did, and in Sub-Saharan Africa the percentages for rural and urban piped water access were 5 and 35 respectively. In Sub-Saharan Africa more than one third of sources not piped onto the living premises require more than thirty minutes of travel and collection time which lead to less water collected and significant economic impacts on the family [17].

3.3.4 Urban/Rural Disparities

Urban/rural disparities account for another significant share of the discrepancies of improved drinking water access worldwide and are interconnected with the problems of population growth. In 1990, 43.5% of the world's population lived in urban areas and by 2000 the number had grown to 47% [19]. 80% of the global population without access to an improved water source lives in a rural setting, more than five times that of the population in urban areas without access in 2008, and the gap widens when only piped water connections are considered [16], [24]. Once again, this is particularly true in Sub-Saharan Africa, as well as Oceania, parts of Asia and Latin America (see Figure 3.3) [16].

While rural water supply improved, urban supply decreased between 1990 and 2000, and as of 2008 urban coverage has barely been able to keep up with the population growth [17], [19]. In addition, the global trend towards urbanization is expected to continue, with Africa being a leader of this trend. The urban African population is predicted to more than double in the next 25 years imposing enormous challenges on the water sector. At the same time, rural areas will face the daunting task of bridging the service gap. If the world is to achieve global coverage by 2025, nearly 3 billion people must gain coverage to improved water supplies at triple the rate experienced between 1990 and 2000 [19].

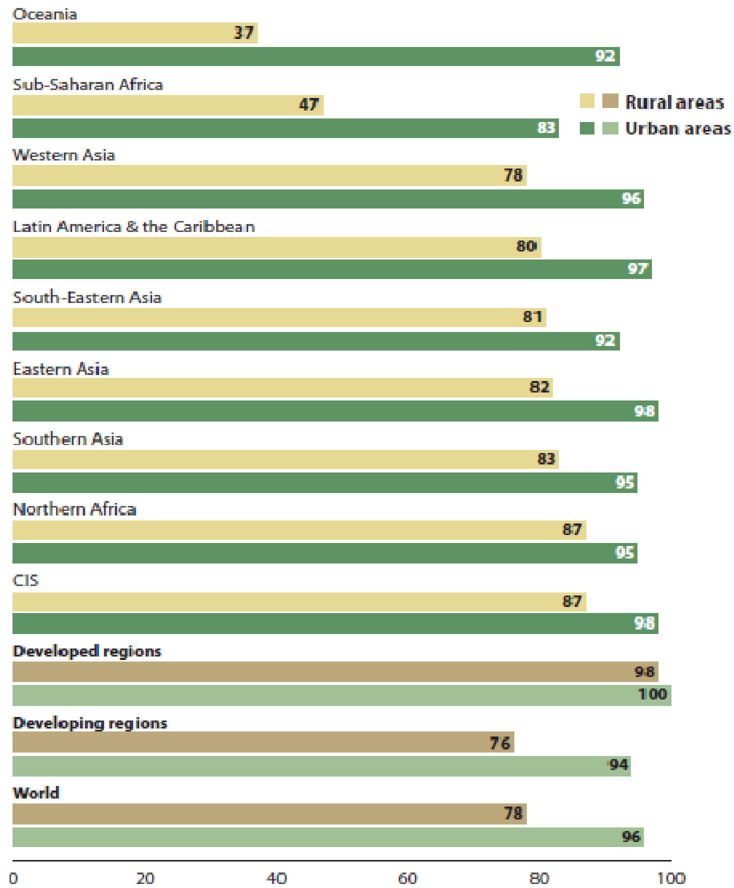

Figure 3.3 Percentage of Population Using an Improved Water Source, 2008 [16]

3.4 Sector Constraints

Many possible constraints exist in the water and sanitation sector and these vary across communities, cities, provinces, and countries. After analyzing the performance and management of the water and sanitation sector in each of the countries it monitors, The JMP recognized the following as the common constraints of the sector:

- Financial difficulties
- Institutional problems
- Inadequate human resources
- Lack of sector coordination
- Lack of political commitment
- Insufficient community involvement

- Inadequate operation and maintenance
- Lack of hygiene education
- Poor water quality
- Insufficient information and communication

When the water and sanitation sector is viewed from a global perspective, four major constraints are recurring themes across every region. These include logistics, funding limitations, inadequate cost-recovery, and inadequate operation and maintenance [19].

The institutional problems, lack of sector coordination, lack of political commitment, and inadequate human resources from the list above often stem from government ineffectiveness or institutional weaknesses in low income countries. These result from a lack of individual professional skills, understaffing, poor motivation, inadequate resources, or poor organizational management [22]. In many countries, the institutions responsible for water are disjointed and do not coordinate through a central agency [19]. For example, water provision may be the responsibility of one institution while quality may belong to another. Lack of commitment at the highest government levels only exacerbates the situation. Even those individuals who are qualified or committed are often limited by the system rather than able to improve it. Corruption, whether perceived or actual, has been underscored as a major threat to the sector [22]. Yet poor institutional support is not inevitable; extremely poor countries such as Burkina Faso, Ghana, and Guatemala have extended water supplies to half their populations [18].

3.4.1 Cost-Recovery

Inadequate cost-recovery is largely caused by water tariffs which do not cover the cost of production. Across all developing regions of the world there is little variation in the median unit production cost of water, averaging \$0.20 to \$0.54 per cubic meter in urban areas. But more than half of these countries price water below their respective median unit production cost. In Africa, for example, the average production cost of water in urban areas is US $0.30 per cubic meter but tariffs cover only approximately 85% of this. Africa claims the second lowest tariff to cost ratio, with Asia being the only region more unbalanced [19].

Cost-recovery can be difficult to achieve from both ends. From the recovery side, one factor is the difficulty in collecting tariffs from certain types of facilities. For example, standpipe use is difficult to monitor and charges may be even more challenging to collect than other types of facilities. Illegal taps into the pipe infrastructure are also common. Construction cost affects the problem from the opposite end, increasing the initial investment requirements. Not only do these costs vary based on facility type and location, immediate water resource endowment, labor costs, material availability, and transportation also make it difficult to anticipate the financial requirement (see Figure 3.4) [19].

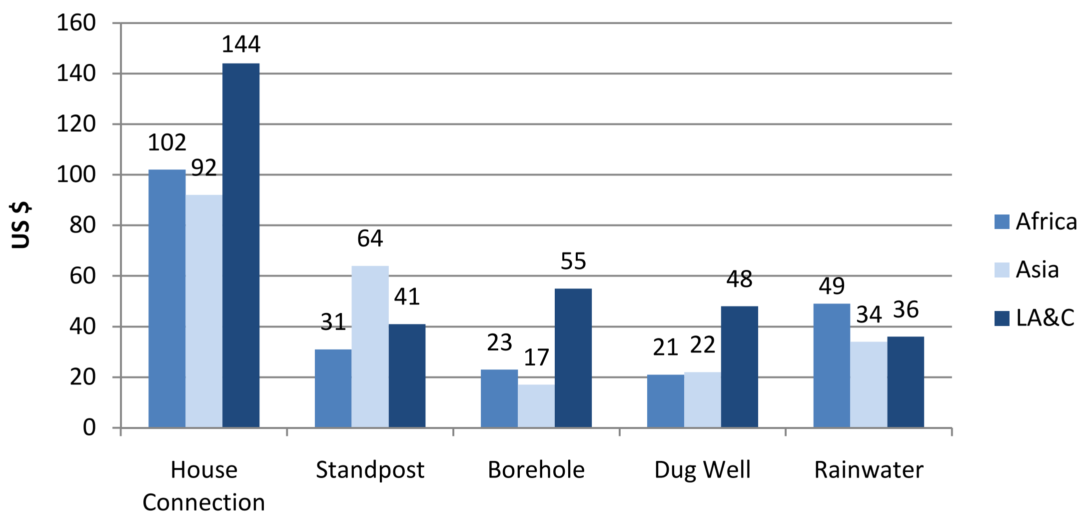

Figure 3.4 Regional Comparison of Average Construction Costs per Person Served by Facility, 1990-2000 [19]

3.4.2 Operations and Maintenance and Intermittent Service

Operations and maintenance is a large, albeit often overlooked, aspect of water supply interventions, and for this reason, a large number of the interventions in developing countries do not last [22]. In a study by Rietveld *et al* [25], a metric was developed to assess the successes and failures of drinking water interventions in South Africa. The study found that of the fifteen villages assessed, three had insufficient water supply because wells had dried up or were insufficient to meet demand. Another five had no water on the day of inspection due to broken pumps, lack of operators, or lack of funding to buy diesel [25]. Other studies suggest that one third of the hand pumps across Sub-Saharan Africa are non-functional and only 64% of the arsenic mitigation technologies used in Bangladesh are operational [22].

In a study on the sustainability of water and sanitation in rural Africa, Montgomery *et al* [26] concluded that operations and maintenance was the measure that improved rural sustainability in nearly all of the countries in their study. They suggest that dynamic operations and maintenance is one of the three components of sustainability in practice, highlighting the importance of a spare part supply, training repair technicians, and ongoing technical support. They also site insufficient financial planning and lack of spare part suppliers as the two major restrictions to effective operations and maintenance, a point which is underlined in a global MDG cost-benefit analysis by Hutton and Bartram [27], [26]. While there is little rigorous research into the impact of dynamic operations and maintenance, many studies agree that it is a critical component of sustainability [28-32].

Intermittent service is also a significant contributor to the inadequacy of operation and maintenance of the water sector worldwide. This may include pressure drops due to power outages or too many illegal taps into the system, or cessation of water flow completely [33]. Intermittent systems are reported to be active for more than half the time, but this figure may disguise the fact that many systems which are rarely operable exist. When systems are not operating or are not reliable, customers often turn to other vendors who generally charge several times more than the formal tariff for water of poor quality and insufficient quantity [19].

More than a third of urban systems in Africa and Latin America and the Caribbean, and more than half of the urban systems in Asia operate intermittently. In most regions rural systems are more reliable, but in Africa it is estimated that 30% of the rural systems are nonfunctioning as well. This number may be even greater as few countries keep accurate records of breakdowns or lapses in operation. "Functioning" is defined as daily operation at greater than 50% of the design capacity for piped systems and 70% for hand pumps. What is more, the classification of "functioning" does not define the quality, location or restrictions on service. In Africa this is largely due to limited water resources, large distances between supplies, and low population densities [19].

Intermittent systems introduce many opportunities for contamination. Containers kept for domestic water storage see greater use when the supply of water is unreliable. But, these containers are often not cleaned regularly or may be left open to the air which creates considerable risk. Having water constraints in the home may also promote poor sanitation practices. Also, when systems function intermittently, intrusion of contaminated groundwater into pipelines may occur through cracks or joints, or pipes may collapse without the support of water pressure causing even greater failures in the system. This matter is discussed further in section 5.2.1.

Even when they are functioning, disinfection is uncommon among urban drinking water systems. Based on countries' self reporting, one in five systems in Africa, Asia, and Latin America and the Caribbean do not disinfect, and two in five systems in the islands of the Pacific do not. This may suggest that lack of education, cost, maintenance, or fear of chlorination byproducts may be factors. Yet the risks posed by lack of disinfection are far greater than those of disinfection byproducts [19].

3.5 Facing the Challenges

Based on UN population projections and the JMP 2010 progress report [17], 75 million more people globally must gain access to improved drinking water sources in the next 5 years to meet the MDG target [19]. In order for Sub-Saharan Africa to meet its *regional goal*, nearly 210 million people must be reached. This means that an average of 42 million people must gain coverage per year for the next five years, at a rate that is nearly 140% of that in experienced the 18 years between 1990 and 2008.

In order to make progress toward these goals new and tailored initiatives must be made with regional goals and conditions as their primary motivation. Major challenges for the water sector will include keeping pace with population growth, narrowing the service gap, and improving service quality. These must be the working points of any program. Additionally, with the high projection of urbanization, more than half of the increased coverage must be focused on urban centers. Yet with the low service density and quality of rural areas, the divide of efforts must be nearly equal [19]. Also, in order to not backslide on the current service gap, substantial attention must be paid to the maintenance of existing systems in addition to the construction of new infrastructure.

An investigation of sector operation and maintenance activities across Africa led the WHO to conclude that among the factors necessary to sustainable water supply projects were community involvement at every stage, political commitment, intersectoral coordination, adequate institutional frameworks, human resources development, community self-improvement, improved information management, use of appropriate technologies, and involvement of the private sector through regulation and control mechanisms. In the 1990s the Operation and Maintenance Working Group established the following principles for improving the sector:

- Water must be treated as a commodity: financially sound but subject to legislation and regulation to ensure its conservation and protection
- The provision of water should be viewed as a service industry
- Services should be set at a level which users are willing to finance, operate, and maintain. [19]

The limitations are largely in infrastructure and financing as discussed previously in the "Sector Constraints" section. The challenge lies in attracting new sources of initial investment and sustaining these. Usually this is done through a collaboration of governments, communities, commerce and civil society and results in shared resources regardless of the technology or scale. Often the initial investment is the easiest to obtain; effective campaigns can gain support for one large investment to build something, but it poses more difficult to maintain financial support [19].

The role of self-help (self-supply) initiatives and small enterprise initiatives in the delivery of improved and sustained water services is also growing. In a recent review, the Bill and Melinda Gates Foundation recognized this initiative as a broad approach to service provision, along with externally driven approaches initiated by agencies other than water users, and enterprise driven approaches in which local private entities supply goods and services to governments, non-governmental organizations (NGOs), and water users directly [22].

Unlike sanitation, it is clear that creating demand for drinking water is not necessary. The need for a safe and reliable source of drinking water is evident to most people, especially those who do not have it. Willingness to pay vendors many times the cost of piped service also demonstrates the value placed on water [19]. In some areas it may be the inability of the utility to extend service, rather than willingness to pay, which is the limiting factor. Governments, NGOs, and the private sector must be aware of the local dynamic and how improvements can best come about working within that dynamic.

3.6 Redefining Success

Currently, targets for success are based upon global averages and 20 year old population estimates. In order to truly succeed in this mission, a more accurate analysis of progress has to be developed on an individual country level and will likely require new definitions of success.

The primary limitation of the MDG for water and sanitation is that it regards people as either ‘haves’ or ‘have-nots’. The target is a pass/fail test in which both the grading standards and the pass rate are low. What’s more, the test is an evaluation of numbers only, not water quality or standard of living, and incentives may not be directed to the best outcomes. For example, even if the MDG for water is met, neither the number of people who do not have access, nor the global burden of disease will be halved [34]. Because there are no intermediate measures of improvement or related reward structures, there is no motivation for improvement beyond the ‘have’ status or for countries near the top or bottom of the spectrum to invest in water. Intermediate targets, such as quality, distance, or person to tap ratios, would incentivize continued progress and reward progress at all levels. It is also important that progress be assessed by the least developed population within a country to ensure focus remains on the most needy [35].

It is well known that water and sanitation are closely interrelated, yet the targets for each of these remain completely independent. Creating benchmarks that connect the two, for example requiring both water and sanitation at the household level, would better represent improvements needed for health and social gains. However, doing so would mean missing both the water and sanitation MDG targets [35].

Correlating these benchmarks with specific health outcomes would further associate water interventions with their true intended end goals of health improvement. It is important that this association not be lost in the attempt to meet the MDGs. Once again, progress will seem more modest when the goal is redefined in this way, but doing so will encourage continued commitment and momentum after the MDG time frame ends in 2015 and ensure that when the target is reached the big picture goal will have been achieved [35].

Finally, the success measured for full social gains should not be limited to the household or measured based on one location. People must drink water, wash their hands, and have clean facilities in locations other than just their households. More comprehensive targets would require access in places such as schools, hospitals, and workplaces [35].

CHAPTER 4

FINANCIAL ASSISTANCE TO THE WATER SECTOR

In recent years, the number of international agreements and financial commitments to the water sector has hardly reflected the amount actually invested dispersed in developing nations. Disbursements are either never given or, more often, less than the original commitment. There is little correlation between where aid is needed and where it is given, and often the aid is not sufficient to meet the needs of the recipient.

Development investment contributions are categorized under the local public sector, the local private sector, the international public sector, and the international private sector. External assistance from the international public sector is given by countries, bilateral and multilateral agencies, NGOs and foundations. Funding may be given as general budget support, sector specific support, or may be directed to a particular project. Aid may come in the form of concessional loans, grants, or credits and may account for up to 90% of the expenditure in the water sector for a given country.

Estimates of the total cost to achieve the MDG have reached up to $75 billion annually [36]. In the mid-1990s, total annual investments in the water and sanitation sector in developing countries were approximately $28 billion. Of this, 65-70% was contributed by the local public sector, 5% from the local private sector, 10-15%, from international donors and NGOs, and 10-15% from the international private sector. As of 2008, total investment was still below $6 billion but international donors increased their commitments by more than $16 billion, while the international private sector reduced their commitments by more than $17 billion [18], [37]. Local public investment in infrastructure was also reduced to decrease expenditure, with the expectation that this decrease would be covered by private sector contributions, but has also led to a decrease in financial support for infrastructure from international multilateral agencies [37].

4.1 Official Development Assistance

4.1.1 Donors and Recipients

Within the total investment, official development assistance (ODA), or international public sector aid contributions to the water and sanitation sector have generally risen between 1995 and 2007 with a decline in the early 2000s. Overall, bilateral aid rose 19% after this decline (2002-2007) and multilateral aid grew by 11%. The largest donors to the sector are Japan (26%), International Development Association of the World Bank (IDA) (15%), and the United States (10%). The major recipients of ODA during this period were Asia with (54%), Africa (33%), Least Developed Countries (LDCs) (23%), and Other Low Income Countries OLICs (38%) (see Figures 4.1 and 4.2) [38].

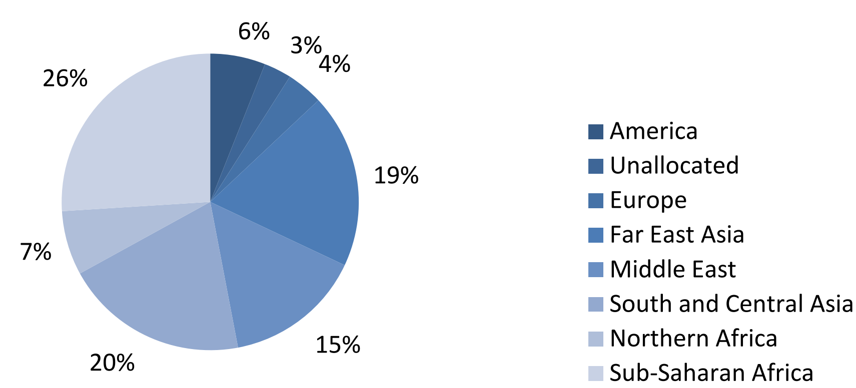

Figure 4.1 Distribution of Aid to WSS by Region, average 2002-2007 [38]

4.1.2 Aid Pathways

Donor agencies use a variety of pathways to direct development aid. One channel, general budget support, allows recipient governments the flexibility to use the aid in the way they deem most appropriate or immediately necessary, and allows for cross-sectoral projects. Specified ODA can assure assistance is given to a particular area and is much easier to track [39]. Many feel that with the majority of aid channeling through the national government, there is a risk that domestic investments will decrease and water sector funds will be diverted for more politically prioritized sectors [37]. For these reasons, donor agencies are generally very cautious in allocating general budget support and do so in very limited forms, depending on the management capacity and domestic agenda of the recipient country. In the last twenty years, general budget support has decreased from approximately 18% to 5% of total ODA. However, since 2001 the Organisation for Economic Co-operation and Development (OECD) has recommended that aid be untied for LDCs and non-LDC highly indebted poor countries (HIPCs) with the claim that this provides a more efficient use of money, increases ownership and alignment with recipient governments, and builds local capacity through the use of local goods and services. The percentage of untied aid to the water and sanitation sector rose from 68% in 1999 to 87% in 2008 [39].

4.1.3 Commitments versus Disbursements

Unfortunately, aid commitments can be unreliable resources. Usually when commitments are made they are acted upon in some way. But they take many years to fully disburse and often actual total disbursements do not equal the original commitments. For example, between 2001 and 2007, a total of US $31.4 million was committed to the water and sanitation sector by 32 bilateral and multilateral agencies who report to the OECD's Creditor Reporting System (CRS). Of those, 31 agencies actually made disbursements, assuming disbursements began and ended one year removed from the commitment period (2002-2008). The total disbursements for 2002-2008 totaled US $22.9 million, approximately 70% of commitments [40]. Figure 4.2 below compares aid commitments and disbursements for the 29 agencies who contributed both. According to 14 reporting agencies, long term commitments of 5 years or more comprised 58% of commitments in 2008, while commitments 3 to 5 years in length accounted for 36% [39].

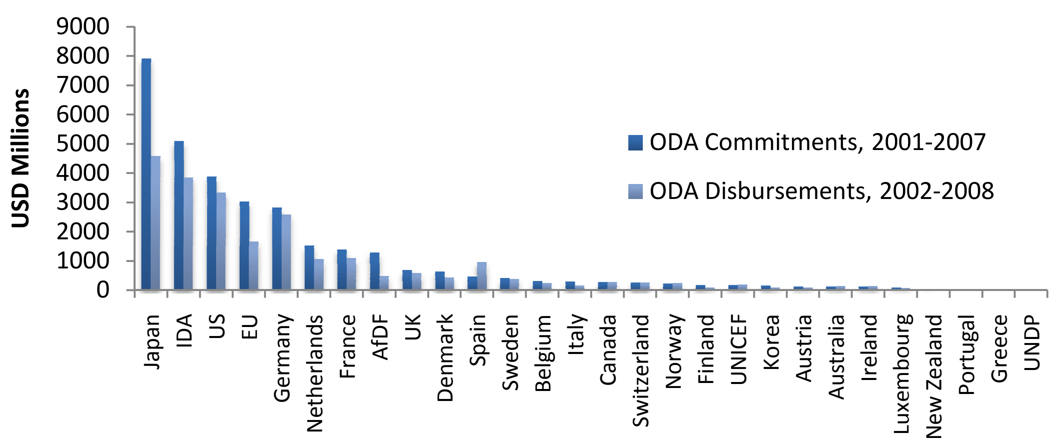

Figure 4.2 Water Sector ODA Commitments vs. Disbursements [40]

4.1.4 Form of Aid Giving

Donors have shown that the form in which they give aid is in part based on the economic status of the recipient country. In general, grants make up the majority of aid to LDCs and OLICs while loans dominate aid to upper and lower middle income countries [39]. The ratio of loans to grants is specific to each donor's aid portfolio. Many countries, such as Japan, give primarily through loans, or give mainly to middle income countries, as is the case with the US, Germany, the European Commission (EC), France, and Spain. They may also have political motivations, such as the United States' support of reconstruction of water infrastructure in Iraq which made up a significant proportion of total Development Assistance Committee (DAC) ODA. Additionally, although a given donor may contribute a high percentage of the water sector ODA, this may be a low fraction of that donor's overall giving, indicating a low priority. The donors that give the greatest percentages of their aid to the water sector are as follows: the African Development Fund (AfDF) (22%), Japan (19%), the Asian Development Fund (AsDF) (17%), the Inter-American Development Bank (IDB) special fund (12%), and Denmark, Netherlands, and the IDA (11% each) [38].

4.1.5 Prioritization and Targeting

Prioritization of the water and sanitation sector in relation to other aid sectors is also generally low, both by donors and developing country recipients. The WHO reports that of 15 responding external support agencies, only four listed water and sanitation as a top three priority out of 12 sector choices. Water was tied for fifth behind health and HIV/AIDS, government and civil society, education, environment and climate change, and poverty and gender. Figure 4.3 below shows the comparison of aid commitments between water and sanitation and other aid sectors. Of US$158 billion in commitments in 2008, only 5% or $7.4 billion was allocated to water and sanitation. This ranks water and sanitation lowest among social sectors, which include health and education. In fact, the late 1990s water and sanitation lead health and education by 1% and 2% respectively and accounted for 8% of total aid. In the years since, these other sectors have continued to grow and now lead water and sanitation with 12% and 7% of aid respectively.

Furthermore, domestic spending on water and sanitation is often less than one half of one percent of the country's gross domestic product (GDP) [39].

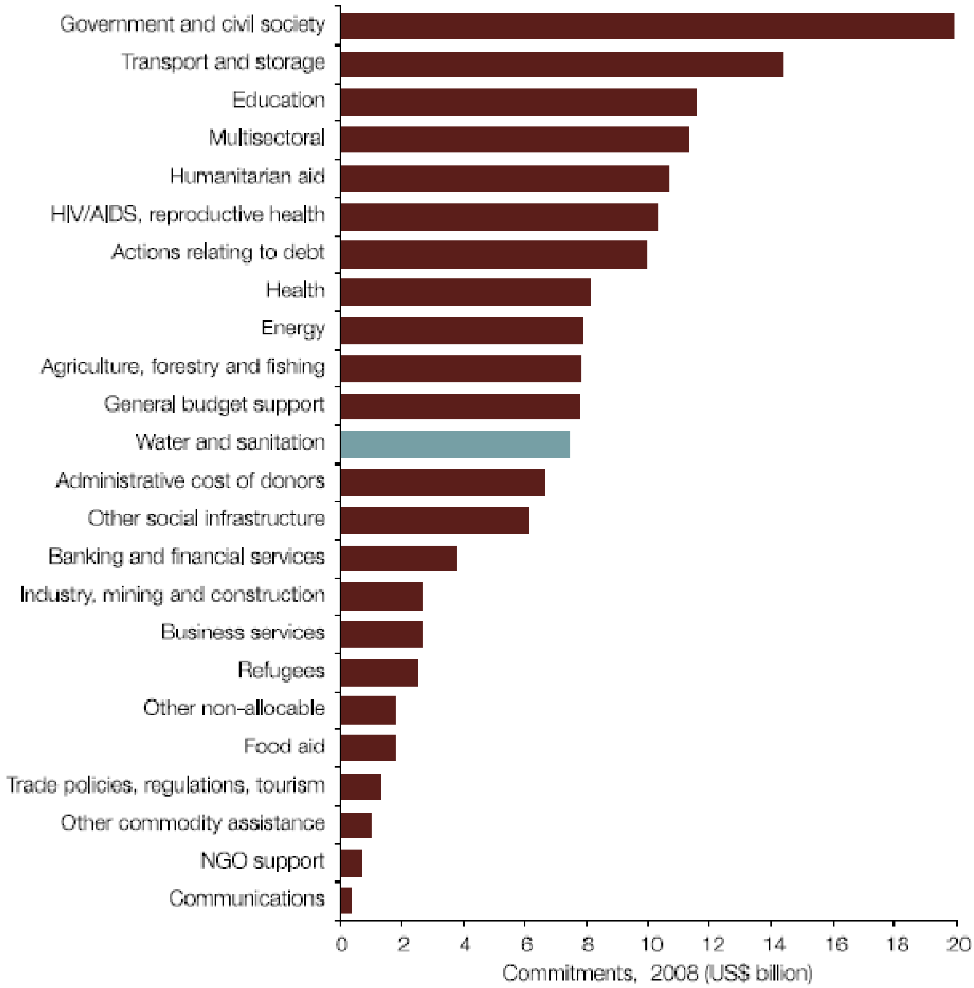

Figure 4.3 Comparison of Water Sector to Other ODA Commitments [39]

There are several factors which affect the targeting of water and sanitation aid. While it is clear that some of these factors are considered by donors when determining the direction of their aid, it seems that others are disregarded. For example, the DAC considers projects to have an 'integrated approach' if they have goals of gender equality, environmental orientation of actions, poverty focus, and good governance and participatory orientation. Donors are expected to qualify these as principle, significant, or not considered, but for all categories other than governance and participation 'not considered' or not reported responses accounted for 67-90% [39].

The first of these factors is impact of aid. Out of twenty countries surveyed in the GLAAS External Support Agency Survey, 12 indicated that they attempt to measure the impact of aid in the receiving country. The most common tool for doing so was a socioeconomic survey, which is used by nearly 90% of the responding donors. Other tools include coverage or access figures, benefit of the poor, process monitoring, budget tracking, poverty reduction, and human development indicators [39].

The second factor is perceived priority. Countries or regions which have been deemed priority by the most agencies receive the greatest amount of aid. The highest ranked 20 receive approximately 45% of aid. Donors have indicated that coverage, poverty levels, and established in-country presence are the three most heavily used to determine priority countries [39]. It is important to note, however, that the criteria for a "priority" ranking are individual to the agency and may or may not be founded on need based indicators.

While agencies have reported that they consider existing water coverage in a country in the allocation of their aid, this is not reflected in their actual commitments. There is a weak correlation between sanitation and drinking water coverage and donor commitments (see Figure 4.4). For the 2006-2008 period, the median per capita aid was US$2.26. Of the 35 countries in the lowest quartile of coverage, 16 received less than this median per capita aid; this is highlighted in the gray box in Figure 4.4. Although donors indicate using coverage as a criterion, it stands to reason that if this were true more of the lowest quartile countries would receive greater than the median per capita aid and there would be a stronger correlation between coverage and aid [39].

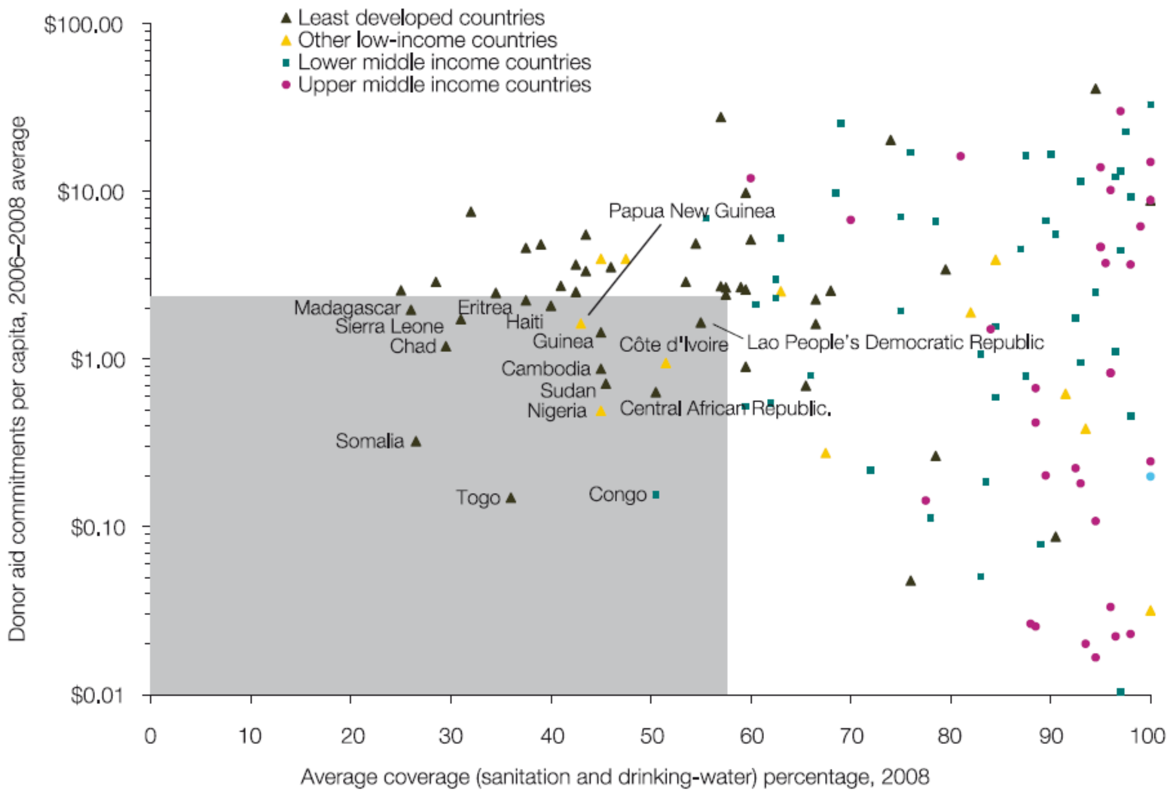

Figure 4.4 Donor Aid Per Capita versus Average Coverage by Country [39]

A third factor is the economic standing of the recipient country. Many agencies aim to give a majority of their aid to LDC and OLIC countries, as is the case with the IDA, the AfDF, and the AsDF.[1] Between 1998 and 2008 the percentage of water sector ODA given to LDCs and OLICs ranged from 32% to 46%, with the remainder given to middle income countries, largely lower-middle income countries (LMICs). Yet, new

[1] 67% of LDCs, 42% of OLICs, and 83% of HIPCs are African countries.

commitments in 2008 aimed to increase the percentage given to lower income countries. Japan and the US have committed an additional US$720 million to LDCs and OLICs which will increase their combined aid from US$226 million to US$948 million (a 300% increase) [39].

Unfortunately, economic standing seems to negatively affect the aid allocation to the unserved proportion of the population in a recipient country as well. Of the top ten recipients of annual aid per capita unserved, all but one are middle income countries and 7 of 10 have greater than 90% use of improved sources. Of the ten countries that receive the least aid per capita unserved, all are least developed or low income countries. The disparity between the highest and lowest aid per capita unserved recipients is 4,570% [39]. Within a country it is the poorest economic class that makes up the majority of the unserved population. Public health statistics show that water and sanitation related illness demonstrate a correlation with personal income levels [19].

It is also clear that sub-sector allocation is an influential factor. The majority of this aid is directed towards large systems. Large systems accounted for more than half of DAC contributions between 2006 and 2007, and 62% of total aid in 2008 [39]. Unfortunately, large centralized systems are often characterized by high capital costs, poor operation practices, and overreliance on expensive treatment technologies that are difficult to maintain [41]. Meanwhile, aid to basic systems has dropped from 27% to 16% of total aid. The Netherlands, the UK, Spain, and Denmark target the greatest proportion of their aid to basic systems [39]. A large portion (64%) of the aid to large systems was in the form of loans. River development was also aided largely in the form of loans (44%). On the other hand, DAC members almost exclusively contributed to basic water and sanitation through grants, and gave predominantly through grants to water resources policy and administrative management, water resources protection, and education and training. Compared to bilateral donors, multilateral agencies focused on policy issues (25%), rather than small systems (4%) or training (0.07%) for water and wastewater [38].

Finally, it seems that donors prefer to give aid to new systems. It is difficult to determine exactly how much of aid is given for the construction of new systems versus the maintenance of existing systems because donors are not required to distinguish between these in their aid reports. It is also difficult to determine if this aid is focused toward achieving the MDGs, by increasing access, or contributing to sustainability and improved quality by maintaining systems already in place. But, in a 2009-2010 GLAAS survey, a small number of donors indicated that 64% of their aid was directed towards the construction of new systems [39].

4.1.6 Adequacy

The adequacy of aid is an important tool in global development which determines whether the quantity of given resources are sufficient to produce the desired target. To determine the adequacy, whether domestically or globally, current and future expenditures must be compared with financial need. Unfortunately, in global water and sanitation development it is very difficult to reliably determine adequacy. Both the estimates of financial flows and need involve knowledge gaps and inconsistent assumptions.

Estimates for the cost of achieving the MDG for water and sanitation access have ranged from US$6.7 billion to over US$75 billion. The ten-fold range includes a variety of assumptions based on starting year, population growth, technology, level of service, and maintenance. Many do not consider the cost of support services or the institutional capacity to ensure that the systems are planned, implemented, and maintained well. There is also a lack of accountable information on funding sources. While OECD flows are generally well reported, donations from non-OECD sources, NGOs, or the private sector are not tracked as well [39].

Despite this, adequacy measures provide a general picture of development progress and allow for comparison between recipients. Table 4.2 below compares the adequacy of drinking water financing across several African nations based on their own assessment of the adequacy of their funding. Of these, only two reported having sufficient funding to achieve the MDG [39].

Within the estimates for the cost to achieve the MDG, funds are often not adequately allocated. Recall that the majority of aid is used to construct new treatment facilities. According to Hutton and Bartram [27], nearly 75% of the costs to achieve the MDG consist of recurrent capital and maintenance of existing services. In their opinion, of the total aid 44% (the largest proportion) should go to recurrent capital and maintenance needs of existing drinking water systems, and 6% to new drinking water coverage with the remainder being allocated to new and existing sanitation facilities [27].

The entirety of the fault does not lie with the donor agencies. Water sector financing in low income countries is often criticized for being inadequate, but the money that is received is often underutilized or inappropriately used as well. The institution receiving the aid may not have sufficient operational funds or organization to quickly distribute funds at the local level. Therefore, the ministry responsible for water may receive delayed or decreased funding [22].

Table 4.2 Adequacy of Drinking Water Intervention Financing [39]

	Urban	Rural
Angola	●	●
Benin	▲	▲
Burkina Faso	▲	▲
Burundi	▲	▲
Cameroon	=	=
Central African Republic	-	-
Chad	▼	▼
Côte d'Ivoire	●	●
Democratic Republic of the Congo	●	●
Ethiopia	-	-
Ghana	●	●
Kenya	▲	▲
Lesotho	▲	▲
Madagascar	▲	▲
Mali	▲	▲
Mauritania	▲	▼
Morocco	▲	▲
Mozambique	●	●
Niger	=	●
Rwanda	▲	▲
Senegal	=	▲
Sierra Leone	●	●
South Africa	●	●
Sudan (south/north)	●●	●●
Togo	●	▼
Uganda	●	●
Tanzania	●	●
Zimbabwe	-	●

Color Key:
● More than 75% of needs
● 50-75% of needs
● Less than 50% of needs
- No information

Shape Key:
▲ Increasing trend
= No change in trend
▼ Decreasing trend
● No trend information

4.2 Private Participation

Private participation is also an important, albeit inconsistent, contributor to the water sector. After the Second World War publicly owned utilities were failing to meet demand, expand services, and reach poor and rural households in developing countries.

Many governments surrendered to pressures to keep prices below costs. In the 1990s, provision of utilities shifted to the public sector and experienced a rapid and widespread growth. This growth peaked in 1997 and has for the most part been declining since. Figure 4.5 below describes the trend in private investment compared with total ODA in the water sector. This is largely due to inadequate cost recovery which resulted from an inability to break the tradition of severe underpricing [42]. Today, in all regions of the world the majority of urban water supplies are still publicly operated with Africa having the least private provision (0% median) and North America having the greatest (45% median) [19].

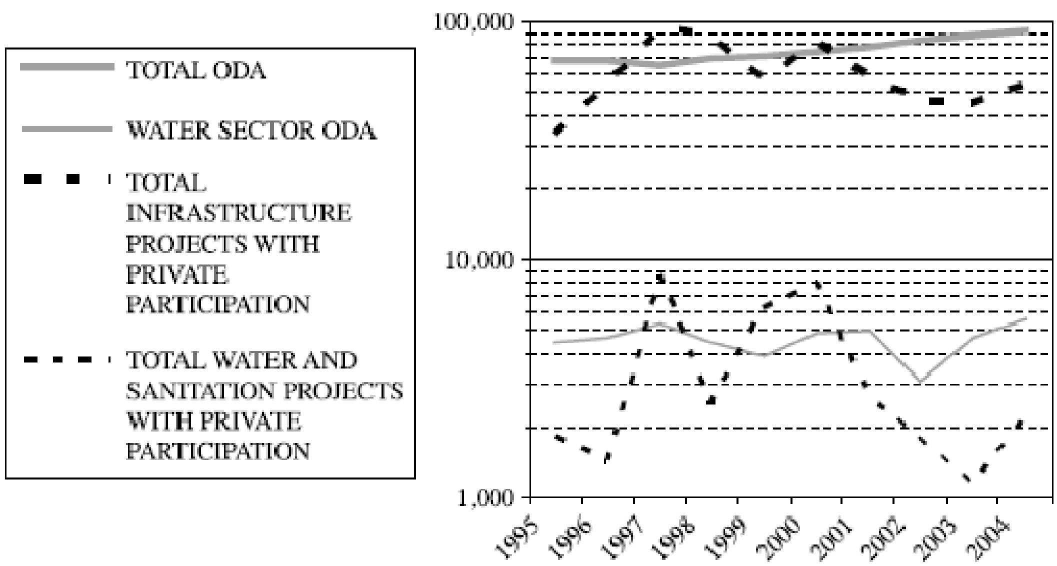

Figure 4.5 Private Participation in Total and Water Sector ODA (Dollar Values in Millions) [37]

For several reasons, it is difficult to accurately estimate private participation in the water sector. First, private donors are not required to report their contributions the same way public agencies do. Databases recording private participation do exist, such as that of the World Bank, but these numbers are compiled from other databases, specialized publications, companies and websites, and are therefore estimates. Also, these numbers give commitments rather than actual disbursements, which may take up to 50 years compared to the 8-10 for ODA disbursements. Further, projects may be listed by complete project costs, all of which may not be privately contributed. Finally, cancellations or renegotiations may not be reflected in the data [37].

According to the estimations of Jimenez & Perez-Foguet [37], between 1995 and 2004 the water sector received 5% of foreign private infrastructure investment. Projects that included private participation totaled US$36.28 billion, but the private contribution alone was approximately US$26.84 billion. A large percentage of this (87%) went to infrastructure, with the remainder going to the purchase of licenses and administrative costs. Additionally, when the estimate that 28% of projects are cancelled or in distress (meaning that the government or operator has requested either contract termination or international arbitration) is considered, the actual private contributions to the water sector between 1994 and 2005 is approximately US$18 billion [37].

The direction and subsector allocation of private funds often experience as many inconsistencies as ODA. Of private sector funds, 98% go to middle income countries, while only 0.95% is sent to Africa. Figure 4.6 below shows the distribution, and depicts how little private participation contributes to the achievement of the MDG. Moreover, investment was directed to only three subsectors: 61% to 145 mixed projects ($153 million), 31% to 102 water projects ($111 million), and 8% to 59 sanitation projects ($46 million). Finally, cancellation or distress status has accounted for a loss of more than US$10 million, the majority of which were large concession water supply projects.

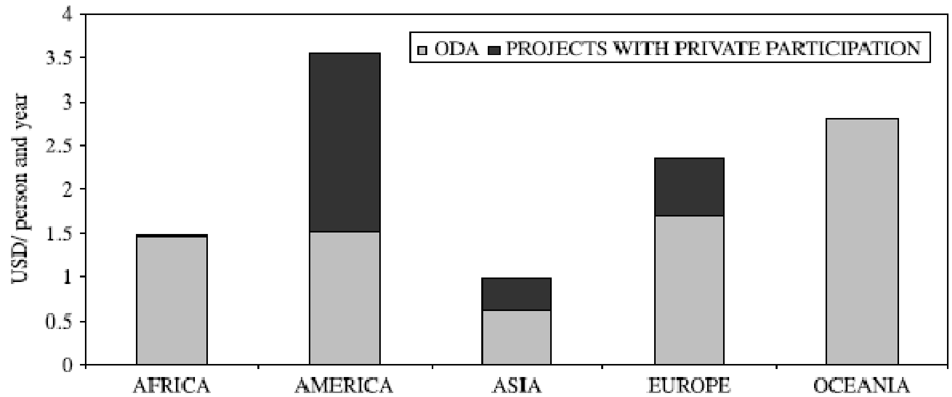

Figure 4.6 Water Sector Public and Private Investment Per Capita [37]

Like ODA, private investment has been insufficient, of low quality, and poorly targeted [37]. There is an indication of the private sector increasing its role in water supply in developing countries once again, but large multinationals do not seem to be contributing much new capital investment, and regulation and return on investment concerns bring questions of stability [19].

CHAPTER 5

WATER AND HEALTH

As a *sine qua non* of human life, and a necessity for proper hygiene, adequate water supply is a matter of public health. The connection between water and health has long been established; as early as the Hippocratic era scholars recognized the interrelation between water, food, and the environment, as well as the way disease prevalence was effected by human behavior [43]. Yet the strength of this correlation has been the subject of many scientific studies and has proved difficult to define. Water related illnesses account for a significant proportion of the global disease burden and thus a great reduction in this burden is possible with improved water treatment and provision. New interdisciplinary approaches may provide a better strategy and accelerate this process.

5.1 Basic Water Requirements

In order to establish the connection between water and health, the quality and quantity of water for basic health requirements are important metrics to define, but this baseline has proved difficult to establish. For example, Howard and Bartram estimate that 7.5 liters of water per capita per day is a sufficient water supply to meet the requirements of most people under most conditions, assuming the water is of a quality of tolerable risk [44]. This estimate does not consider needs other than basic consumption, such as food production, economic activities, or health care. The Joint Monitoring Programme for Water Supply and Sanitation (JMP) of the United Nations Children's

Fund (UNICEF) and the WHO describes an adequate supply as *"the availability of at least 20 litres per person per day from a source within one kilometre of the users dwelling"*, which includes a requirement of location [19]. The World Health Organization also describes safe drinking water as that which *"does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages"* [45].

These descriptions demonstrate the large variation in the definition of basic requirements based on the level of activity considered. Distance and time of travel to an access point, reliability, and cost also affect accessibility. Therefore further subdivision of requirements based on similar assumptions is important in order to create a more consistent basis for comparison. In their 'Drawers of Water' study [46], White *et al* defined categories of water requirements as:

- Consumption (drinking and cooking)
- Hygiene (personal and domestic cleanliness)
- Amenity Use (for example, lawn watering or car washing) [46]

Howard and Bartram modified the definition by adding a separate "Productive" category which separates from amenity uses those which are used to generate income, such as farming, animal raising, brewing, and construction [44].

5.1.1 Consumption

Within the consumption category, estimates suggest volumes from 2 to 25 liters for drinking based on age, gender, body weight, climate, occupation, and health status [44], [46-49]. Lack of adequate water for consumption may result in dehydration, as well as urinary stones, oral health problems, coronary disease and certain types of cancer [50].

If additional water required for cooking purposes is also considered in this category, the minimum rises to the 7.5 liters suggested by Howard and Bartram previously [44].

Quality of water for consumption is largely affected by the presence of chemicals or pathogens in the water. Of the chemical risks, arsenic and fluoride are the greatest contributors to the disease burden. Although all of these are naturally occurring, they are often the largest concerns in developing world settings where synthetic and complex organic chemicals are less prevalent. Arsenic contamination is an increasing concern globally, especially in Bangladesh where between 35 and 77 million people are estimated to be at risk. Fluorosis is also a large problem in China and India and is estimated to affect 70 million people worldwide. Table 5.1 below lists the guidelines suggested by the WHO for water quality in conventional treatment plants, including arsenic and fluoride guidelines. Other chemicals of significant risk include nitrate, lead, selenium, and uranium [45].

Table 5.1 WHO Guidelines for Common Contaminants [50]

Arsenic	0.01 mg/L (P)
Fluoride	1.5 mg/L
Nitrate	50 mg/L
E. coli	0/100 mL[a]
Thermotolerant coliforms	0/100 mL[a]
Turbidity	0.1 NTU (S)

(P) = Provisional guideline value
(S) = Suggested guideline value. There is currently no specific guideline for turbidity.
a In communities where the water supply fails to meet this guideline, the WHO suggests using a grading scheme based on the percentage of negative samples. Total coliform is not considered an appropriate indicator for fecal contamination because many bacteria of no significance occur naturally, especially in tropical waters.

The majority of water related health problems in the developing world are caused by microbial contamination rather than chemical. The WHO cites microbial hazards as the primary concern in both the developed and developing world [45]. But the tolerances for microbially "safe" drinking water are, once again, difficult to define. In 'Guidelines for Drinking-Water Quality', the WHO describes adequate quality as that *"suitable for human consumption and for all usual domestic purposes, including personal hygiene"* [51]. This description is not quantitative and does not provide any working metrics. Also, the WHO does not set global standards for drinking water quality; only the guidelines such as those listed previously in Table 5.1 are provided. The guidelines state that, "*WQTs [water quality targets] in terms of pathogens serve primarily as a step in the development of performance targets and have no direct application"* [24].

Instead, the WHO uses a risk-benefit approach, known as a Water Safety Plan (WSP), to analyze the risks throughout an entire water supply, including catchment, source, and point of use, and then managing the associated risks. Microbial quality is assessed through the *E. coli* and thermotolerant coliform indicators shown previously, or through pathogen density testing for a given known pathogen. While the presence of *E. coli* generally demonstrates fecal contamination, the presence of coliform does not and a negative test does not necessarily point to a lack of contamination, as some viruses and protozoa are more resistant to disinfection. Because of this, these measures are unreliable assessments of water quality [50].

Health-based targets are often the more appropriate approach to microbial hazard regulation. These targets measure the quantifiable reduction in the overall level of disease in a given area. They are most applicable where adverse affects follow shortly after exposure and are frequently and reliably monitored, but they are limited where risk-exposure relationships are not well understood, which is still the case for many common water associated pathogens. It is important to note that health outcome targets cannot distinguish between water related interventions and those that may also result in a reduced disease burden, such as improved food, air, or hygiene [24].

The location of a water source and the collection time also affect water used for consumption. As mentioned previously, the JMP defines reasonable access to water as *"the availability of at least 20 litres per person per day from a source within one kilometre of the users dwelling"* [19]. Yet a survey of 160 million people (the majority of whom were women) from 39 African countries showed that collection of one container of water took significantly longer than 30 minutes [34]. Therefore intermediate levels of access must be defined. Table 5.2 below provides a better means of describing the living conditions of a particular village or household through four levels of access. This table provides a direct correlation between access level and level of health concern based on the volume of water likely to be collected, and it takes an important step towards specifically coordinating health outcomes with measurable water attributes. Unfortunately, no distinction of the quality of the source is made. Additionally, the link between sanitation and safe drinking water is well known, but there is little correlation between the criteria listed in Table 5.2 below and the related levels of access to sanitation. In order to achieve a more health-oriented definition of access to water supply these must be more closely integrated [44].

Table 5.2 Service Level Defined by Distance and Time to Water Source, Quantities of Water Collected, and Level of Health Concern [50]

Service Level	Distance to Source and Total Collection Time	Approximate Quantities Collected	Level of Health Concern
No Access	>1000m >30 min	Very Low Less than 5L/capita-day	Very High Hygiene not ensured, consumption needs may be at risk. Quality difficult to ensure
Basic Access	100-1000m 5-30 min	Low Unlikely to exceed 20L/capita-day	Medium Not all water needs may be met. Quality difficult to ensure
Intermediate Access	On-plot, e.g., single standpipe on compound or in house	Medium Around 50L/capita-day	Low Most basic hygiene and consumption needs met. Quality more readily ensured.
Optimal Access	Multiple taps in house	Varies Likely to be 100L/capita-day, possibly up to 300L/capita-day	Very Low All uses met. Quality readily ensured

An assumption made in table 5.2 is that greater access equates to increased volume collected. Many studies have supported the conclusion that a closer water sources improve health. Bukenya and Nwokolo showed that in Papua New Guinea a standpipe at the household level resulted in less diarrhea than experienced by users of a communal water source, and that this was true across all socioeconomic classes [52]. Additionally, Gorter *et al* [53] found that Nicaraguan children living within 500m of a water source had 34% less diarrhea than their peers who did not live within 500m of a source. However the proximity within 500m did not contribute any additional health improvement [53]. Similarly, a study by Water and Environmental Health at London and Loughborough [54] suggests that there was no significant change in the volume of water collected between springs or hand pumps, and stand pipes (approximately 15.5 L/c/d) once users have access to an improved source within one kilometer. When yard taps were available the volume increased to 50 L/c/d and with one or more taps within the household the volume of water collected more than tripled to 155 L/c/d [54].

5.1.2 Hygiene

The quantity of water required for hygiene is much greater than that of consumption. Activities in this category include hand and food washing, bathing, and laundry. Because the scale of the correlation between water and health has proved difficult to determine resolutely, it is impossible to effectively place a minimum on the water requirements for proper hygiene. It is important that sufficient quantity is available to remove dirt and soap during bathing in order to prevent further health concerns and to ensure regular bathing using a safe water source. The regular washing of clothes and eating utensils may also be affected by poor water availability. If water for hygiene is not readily available, hygienic practices such as hand washing may be delayed, allowing time for pathogenic transmission in the mean time. Different sanitation technologies also have varying water requirements [50]. The influence of water on hygiene and health has driven the search for quantifiable evidence of health burden reductions. These reductions are important to financially limited populations in order to receive the greatest health improvements [44]. They are discussed in further detail below.

5.2 The Scientific Connection between Water and Health

The connections between water supply, poor hygiene, and health have been a subject of considerable discussion for decades. Most of these studies correlate water and sanitation hygiene specifically with diarrheal disease morbidity due to its prevalence among water related illness. The anthology of studies conducted numbers in the hundreds but few have been sufficiently rigorous to allow quantified estimations of disease reductions to be made. The two Esrey reviews described below have long served as a seminal voice on the subject. A few recent studies have updated the findings of the Esrey reviews and provided some additional insight.

Esrey *et al* [55], for example, conducted a review of 67 studies from 28 countries which investigated the relationships between water quality, water availability, and excreta disposal and the incidence of diarrheal disease in children. Of the 67, 44 provided quantifiable reductions based on specific interventions [44]. The results suggested improvements ranging from 48-100% and were most effective with a combination of interventions. They are summarized in Table 5.3 below.

Table 5.3 Summary of Results from Esrey *et al* (1985) [55]

Type of Intervention	Number of Studies	Percentage Reduction	
		Median	Range
All	53	22	0-100
Improvement in water quality	9	16	0-90
Improvement in water availability	17	25	0-100
Improvement in water quality & availability	8	37	0-82
Improvement in excreta disposal	10	22	0-48

In a second review, Esrey *et al* [56] reviewed 144 studies from which 56 were considered rigorous and 24 provided quantifiable morbidity reductions. These assessed the relationship between several specific water related diseases, diarrheal disease among them, based on water quality, water quantity, sanitation and hygiene. The study found a health benefit in water quality and quantity interventions where the water was delivered via a piped system into or near a household (63% reduction in diarrheal disease). However, this review resulted in lower reductions in diarrheal diseases for combined water quality and quantity than either of these factors individually, which is counterintuitive and contradicts the previous review [44]. The results are shown below.

Table 5.4 Results of Esrey *et al* (1991) [56]

Factor	All Studies		Rigorous Studies	
	Number	Median Reduction %	Number	Median Reduction %
Water and sanitation	7	20	2	30
Sanitation	11	22	5	36
Water quality and quantity	22	16	2	17
Water quality	7	17	4	15
Water quantity	7	27	5	20
Hygiene	6	33	6	33

The importance of access at the household level has proven to be a significant conclusion. Health gains from water supply access have shown to occur in two increments, the first in achieving basic access where volumes required for human consumption and limited hygiene are met, and the second when water is available at the household level where the volumes used for consumption and hygiene significantly increase and time savings allows for greater productive and family care activities. Maximum health benefits are likely to be achieved by focusing resources and efforts in providing or upgrading access at the household level rather than directing efforts towards ease of access to a source outside the household, and it should be the policy of governments and NGOs to base measurements and future efforts on improved sources at the household level [44].

There are several explanations for the conclusion that interventions do not have additive properties. The studies considered in the review were not age specific, a factor which the authors note has shown to affect the distribution of benefits [44]. Additionally, it may be true that confounding factors become increasingly influential when interventions are combined [41]. Primarily, these studies exhibit a great deal of heterogeneity. All are characterized by unique locations, metrics, populations, initial water conditions, and filtration technologies [55]. Therefore, it would be unwise to draw any general conclusions from this review and conclusions drawn from the median results of all studies do not reflect the findings of any given study for a particular intervention and location. These results seem to highlight the impact of local conditions and prevalent route of exposure on the scale and impact of a given intervention in a given area. As Prüss and Havelaar note, the exposure-risk relationships of many diarrheal diseases are not well understood which makes it difficult to accurately attribute outcomes to any mode of transmission [44].

In 2005, Fewtrell *et al* [57] contributed a systematic review and meta-analysis of the effectiveness of water quality, water supply, sanitation, and hygiene interventions in reducing illness which updated the findings of the Esrey reviews. Fewtrell *et al* concluded that while their results did not contradict the findings of earlier studies, water quality interventions proved to be more effective than previously depicted. Microbial quality interventions at the point of use specifically were found to be very effective, likely because of the reduced need for water transport and storage which introduce opportunities for contamination. Furthermore, they found that multiple interventions did not have additive effects; a phenomenon not unlike that concluded by Esrey. As possible explanations for this, Fewtrell *et al* cite a fragmented implementation of planned intervention programs due to less effort given to those aspects of the program with lower perceived importance or effectiveness, and lack of assurance of water quality at the point of consumption [57].

Clasen *et al* [58] provide a fourth influential systematic review on the subject. This study is similar to those of Esrey *et al* and Fewtrell *et al* but uses a broader search strategy than the Esrey reviews, and includes unpublished studies but excludes interventions against epidemic diarrhea unlike the Fewtrell *et al* review. It focuses on the effects of household interventions. Yet Clasen *et al* found similar results to the previous reviews. This review concluded that microbial quality interventions were effective in reducing endemic diarrhea, and note that the evidence was compelling despite significant heterogeneity among the studies. They also found that household interventions were more effective than source based interventions, and that effectiveness was related to the level of compliance with the intervention. Furthermore, it was concluded that water quality interventions did not need to be combined with other types of interventions, such as improved sanitation, hygiene, storage, or improved source, but were equally effective as standalone interventions. Quite significantly, they found that evidence could not rule out additional benefit from combined interventions, but called into question the cost effectiveness of integrated approaches in terms of health outcomes [58].

5.2.1 Evidence of Negative Health Impacts due to Poor Water Service

The studies discussed previously provide the defining voice on the potential of water based interventions to affect health outcomes. But these studies have not assessed whether the drinking water supplies provided to people in low income countries have actually delivered their intended health goals or whether they are even still functional; they have only assessed their potential to do so. A study by Hunter *et al* [59] provides this missing information and explores the related health impacts. As discussed previously in the Status of Global Water section, more than a third of urban and more than 30% of rural water systems in Africa operate intermittently. The Hunter *et al* study agreed with this finding and further concluded that there are increased health risks associated with this. Among their conclusions was the finding that even a short disruption in supply of drinking water was sufficient to destroy the health benefit of using an improved source. For example, on days when the consumer drank raw water as opposed to treated water, the probability of infection was calculated to increase from 0.006 to 0.858 for rotavirus, from 0.003 to 0.4 for cryptosporidium, and from 0.000002 to 0.012 for Enterotoxigenic *E. coli* [59].

In piped systems, when water supplies are not functioning, the pressure drop creates a vacuum which sucks contaminated material through cracks in the pipes and allows for fecal contamination [60]. Therefore, the risk associated with a temporarily inoperable system extends beyond consumers having to resort to unimproved sources during that time; the pause in service itself contributes additional health risks. While it may be easier to expand service by constructing new water supply systems, it is much more difficult to ensure these continue to operate in the long term [22]. Hunter *et al* suggest that if new water infrastructure is so unreliable and likely to fail, it will have little health benefit and may have a much lower economic value than anticipated leaving the better management and expansion of existing infrastructure as the more economic option [59].

5.3 Burden of Disease and DALYs

The incidence and burden of disease for water-related illness strongly support both the correlation between water and health, and the need for greater priority of water interventions for the purpose of health improvements. The data below shows that among the conditions considered, water-related illnesses claim a significant share of the global burden of disease (GBD), and moreover that this is especially true in Africa.

The incidence of a disease measures the number of new instances a particular illness occurs. These numbers help to make temporal or geographic comparisons of the risk of disease. Table 5.5 below describes the disease incidence for several prevalent conditions by region. Because diarrheal disease often affects the same person repeatedly, the number in the table below represents the number of episodes rather than new cases. Right away, diarrheal disease stands out as having the largest numbers in the table across all regions of the world.

It is important to note that because the incidence only describes new cases, it gives no indication of how many people are sick at any given time (known as prevalence), the percentage of people within a population who become ill, or the level of effect the disease has on a person's life. The conditions listed in Table 5.5 stem from a range of causes and pose different health risks. Some arise quickly while others are take longer periods to develop; some are mild while others are severe or life threatening; some affect specific age groups, genders, or other demographics; some are more debilitating than fatal. In order to compare them, a common metric is needed which is ignorant of the disease agent or hazard but considers the different risk, severity, and duration of the disease [24].

Table 5.5 Incidence (millions) of selected conditions by WHO region, 2004 [61]

	World	Africa	The Americas	Eastern Mediter-ranean	Europe	Southeast Asia	Western Pacific
Tuberculosis[a]	7.8	1.4	0.4	0.6	0.6	2.8	2.1
HIV[a]	2.8	1.9	0.2	0.1	0.2	0.2	0.1
Diarrheal disease[b]	4620.4	912.9	543.1	424.9	207.1	1276.5	1255.9
Pertussis[b]	18.4	5.2	1.2	1.6	0.7	7.5	2.1
Measles[a]	27.1	5.2	0.0[e]	1.0	0.2	17.4	3.3
Tetanus[a]	0.3	0.1	0.0	0.1	0.0	0.1	0.0
Menengitis[b]	0.7	0.3	0.1	0.1	0.0	0.2	0.1
Malaria[a]	241.3	203.9	2.9	8.6	0.0	23.3	2.7
Dengue[b]	9.0	0.1	1.4	0.5	0.0	4.6	2.3
Lower respiratory infection[b]	429.2	131.3	45.4	52.7	19.0	134.6	46.2
Complications of pregnancy:							
-Maternal hemorrhage	12.0	3.0	1.2	1.6	0.7	4.0	1.4
-Maternal sepsis	5.2	1.2	0.6	0.7	0.3	1.7	0.6
-Hypertensive disorders	8.4	2.1	0.8	1.2	0.5	2.8	1.1
-Obstructed labor	4.0	1.1	0.1	0.5	0.0	1.9	0.4
-Unsafe abortion	20.4	4.8	4.0	2.9	0.5	7.4	0.8
Malignant neoplasm	11.4	0.7	2.3	0.5	3.1	1.7	3.2
Congestive heart failure[c]	5.7	5.7	0.8	0.4	1.3	1.4	1.3
Stroke, first ever	9.0	0.7	0.9	0.4	2.0	1.8	3.3
Injuries[d] due to:							
-Road traffic accidents	24.3	4.7	2.2	2.8	1.8	8.6	4.1
-Falls	37.3	2.8	3.3	3.6	5.3	14.4	8.0
-Fires	10.9	1.7	0.3	1.5	0.8	5.9	0.7
-Violence	17.2	4.5	5.9	2.0	1.6	2.2	1.0

a New cases
b Episodes of illness
c Incidence due to rheumatic heart disease, hypertensive heart disease, ischemic heart disease or inflammatory heart disease.
d Incidence of injuries severe enough to require medical attention.
e An entry of 0.0 in the table refers to an incidence of less than 0.05 million (less than 50 000).

In the early 1990s the WHO began an initiative to quantify the GBD for the world's most prevalent and debilitating diseases using such a metric. The Disability Adjusted Life Year (DALY) provides such a measure and calculates the number of years of healthy life loss due to the disability or death caused by a disease. The DALY weights the duration of the illness by the severity of health effects from 0 (full health) to 1 (death). Many diseases cause disability prior to death so the DALY may also be the sum of the years of life lived with disability (YLD) and years of life lost (YLL). Comparison of DALYs therefore provides a comparison of the burden of disease among different conditions in a given area and allows for priority setting in health measures [24].

Table 5.6 below lists the top ten causes of death and DALYs for both the world overall and for the collection of low income countries. Diarrheal disease lists in the top ten in all four categories. This category includes cholera, typhoid and paratyphoid fevers, shigellosis, amoebiasis, and other bacterial, viral, and protozoal intestinal infections including *E. coli*, giardia, cryptosporidium, rotavirus and adenovirus (see ICD-10 codes A00, A01, A03, A04, A06-A09). They claim nearly 3.7 percent of the world's deaths and 5% of the world's DALY's. In low income countries the numbers are even grimmer: 6.9% of deaths and 7.2% of DALYs are caused by diarrheal diseases. Together these numbers testify to the weight diarrheal diseases on the world's wellbeing and yet they are not inclusive of all water-related diseases [61].

Table 5.7 disaggregates the numbers further into deaths and DALYs for a few different water-related diseases in the world and Africa specifically. Here again, diarrheal diseases account for the majority in all four categories. In Sub-Saharan Africa, 12% of the health budget is used to treat these diseases [62]. What's more, the number of diarrheal disease DALYs for both Africa and the world as a whole rose between 2000 and the 2004 numbers in the table. All combined, those water-related illnesses which are listed in the table account for a staggering percentage of deaths and DALYs. They are responsible for more than 5% of the world's deaths and more than 119 million DALYs. In Africa they cause 16.4% of deaths and 18.3% of DALYs [61]. When all causes are considered, including those not listed in the table, up to 80% of the illness and death in the developing world is water related [63].

The fact that diarrheal disease morbidity is rising despite increasing coverage of water and sanitation hygiene interventions has raised suspicion that these are not contributing to health benefits. Bartram *et al* [34] suggest several reasons for this. First, coverage is not expanding as rapidly as would be hoped or as some official figures suggest. Second, the diarrheal morbidity data may be interpreted in different ways. Variations in study design may cause geographic disparities. Finally, because the bacteria that cause diarrhea may manifest illness in other ways, reducing the bacterial risk could reduce mortality without necessarily reducing morbidity risk [34].

Table 5.6 Leading Causes of Death and DALYs by Income Group, 2004 (adapted from [61])

Disease or injury		Number (10^6)	% of Total	Disease or injury		Number (10^6)	% of Total
World				Low income countries			
Deaths							
1	Ischemic heart disease	7.2	12.2	1	Lower respiratory infections	2.9	11.2
2	Cerebrovascular disease	5.7	9.7	2	Ischemic heart disease	2.5	9.4
3	Lower respiratory infections	4.2	7.1	3	Diarrheal disease	1.8	6.9
4	COPD	3.0	5.1	4	HIV/AIDS	1.5	5.7
5	Diarrheal diseases	2.2	3.7	5	Cerebrovascular disease	1.5	5.6
6	HIV/AIDS	2.0	3.5	6	COPD	0.9	3.6
7	Tuberculosis	1.5	2.5	7	Tuberculosis	0.9	3.5
8	Trachea, bronchus, lung cancers	1.3	2.3	8	Neonatal infections[a]	0.9	3.4
9	Road traffic accidents	1.3	2.2	9	Malaria	0.9	3.3
10	Prematurity and low birth weight	1.2	2.0	10	Prematurity and low birth weight	0.8	3.2
DALYs							
1	Lower respiratory infections	94.5	6.2	1	Lower respiratory infections	76.9	9.3
2	Diarrheal diseases	72.8	4.8	2	Diarrheal disease	59.2	7.2
3	Unipolar depressive disorders	65.5	4.3	3	HIV/AIDS	42.9	5.2
4	Ischemic heart disease	62.6	4.1	4	Malaria	32.8	4.0
5	HIV/AIDS	58.5	3.8	5	Prematurity and low birth weight	32.1	3.9
6	Cerebrovascular disease	46.6	3.1	6	Neonatal infections and other [a]	31.4	3.8
7	Prematurity and low birth weight	44.3	2.9	7	Birth asphyxia and birth trauma	29.8	3.6
8	Birth asphyxia and birth trauma	41.7	2.7	8	Unipolar depressive disorders	26.5	3.2
9	Road traffic accidents	41.2	2.7	9	Ischemic heart disease	26.0	3.1
10	Neonatal infections and other[a]	40.4	2.7	10	Tuberculosis	22.4	2.7

a This category also includes other non-infectious causes arising in the perinatal period apart from prematurity, low birth weight, birth trauma and asphyxia. These non-infectious causes are responsible for about 20% of dalys shown in this category.

Table 5.7 Water-related Disease Death and DALYs Globally and in Africa, 2004 (adapted from [61])

Disease or injury	Number (10^3)	% of Total	Disease or injury	Number (10^3)	% of Total
World			Africa		
Deaths					
Diarrheal disease	2,163	3.7	Diarrheal disease	1,005	8.9
Malaria	889	1.5	Malaria	806	7.2
Schistosomiasis	41	> 0.1	Schistosomiasis	36	0.3
Lymphatic filariasis	0	0	Lymphatic filariasis	0	0
Onchocerciasis	0	0	Onchocerciasis	0	0
Dengue	18	> 0.1	Dengue	0	0
Japanese encephalitis	11	> 0.1	Japanese encephalitis	0	0
Trachoma	0	0	Trachoma	0	0
Ascariasis	2	> 0.1	Ascariasis	0	0
Total	3,124	5.3	Total	1,847	16.4
DALYs					
Diarrheal disease	72,777	4.8	Diarrheal disease	32,203	8.6
Malaria	33,976	2.2	Malaria	30,928	8.2
Schistosomiasis	1,707	0.1	Schistosomiasis	1,502	0.4
Lymphatic filariasis	5,941	0.4	Lymphatic filariasis	2,263	0.6
Onchocerciasis	389	> 0.1	Onchocerciasis	375	> 0.1
Dengue	670	>0.1	Dengue	9	> 0.1
Japanese encephalitis	681	> 0.1	Japanese encephalitis	0	0
Trachoma	1,334	> 0.1	Trachoma	601	0.2
Ascariasis	1,851	0.1	Ascariasis	915	0.2
Total	119,326	7.8	Total	68,796	18.3

5.3.1 Children

While most of the attention in the health sector globally goes to the “big three” – HIV/AIDS, malaria, and tuberculosis – diarrheal disease is responsible for more deaths in children each year than these three combined [34]. For this reason, water improvements may directly impact the achievement of another MDG: to reduce by two thirds the under 5 mortality rate. Nearly 90% of infectious diarrhea is borne by children, and 17% of the 10.4 million deaths among children under the age of five worldwide are caused by diarrheal disease leading to more than 1.7 million preventable deaths annually [64], [61]. Among these 10.4 million deaths, 45% occur in Africa making the death rate for under fives almost double that of the next highest region. Figure 5.1 below depicts the proportion of under 5 deaths that belong to 3 regions by cause in 2004. Note that the table does not compare the severity of the diseases among themselves in a given region, but solely provides the proportion of deaths for the causes listed that each region claims. Africa is responsible for the largest proportion of deaths due to diarrheal disease in the world, leading South-East Asia by approximately 10%.

Once again, studies show that hygiene is largely influenced by the location and availability of water. Prost and Négrel [65] suggest that water used for children’s hygiene was dependent on the availability and collection time. They found that reducing the travel and waiting time for water collection from 5 hours to 15 minutes resulted in a 30 fold increase in water used for child hygiene. This time savings would also likely result in more time spent on child feeding, food preparation, and better family hygiene [65].

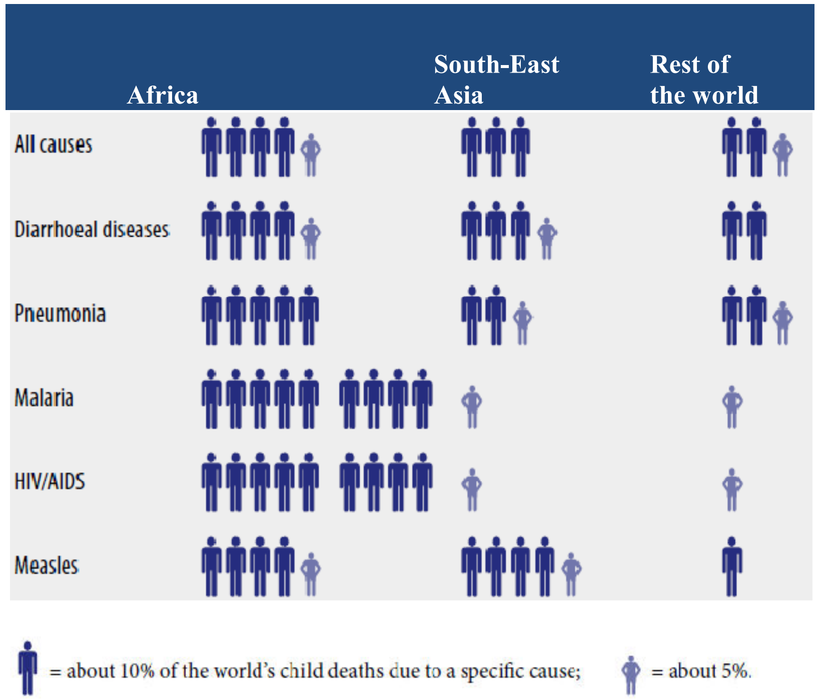

Figure 5.1 Distribution of Under 5 Deaths by Cause and WHO Region, 2004[61]

Studies show that the focus on acute diarrheal illnesses significantly underestimates the disease burden caused by poor water and sanitation, especially in children. Chronic conditions may have a stronger effect on malnutrition, poor education, and stunted physical growth which prevent children from reaching their full potential. Guerrant *et al* [66] suggest that the disability component of the DALY calculation is undervalued because the long term effects are not well documented. If even 5% percent of the children who suffer 4-8 diarrheal episodes in their first two years of life are considered to have a mild life-long disability, the currently estimated DALYs could be doubled, and for every 5% increase in the proportion of children at risk 100 million DALYs would be added to the total [66].

5.3.2 Indirect Associations of Water and Health

In addition to the immediate effects, there are many ways in water affects health in a more indirect manner. For example, in developing countries livelihoods are often made through agriculture or crafts which require water. As mentioned previously in the "Diseases Associated with Water" section, some water-related illnesses can be passed through food crops which are treated with contaminated water. Or, water may be scarce so that the production of crops or crafts is stunted. Because of this, less money is available for nutritious foods and healthcare.

On this note, lack of clean water can also lead to disease indirectly through malnutrition. 29% of the global burden of disease is attributable to diseases associated with malnutrition that may be prevented by diarrheal disease reductions [64]. Tompkins *et al* found that in pre-school aged children in rural Nigeria wasting (<80% Weight/Height) was common among those with poor unprotected water supplies [67]. Many authors argue for irrigation through water harvesting and clean water provision as a means of increasing food production and reducing the disease burden [68], [69]. Examples have shown that access to a small plot of irrigated land improves food security for otherwise vulnerable households in Sub-Saharan Africa and south Asia [69]. Kirogo *et al* found that higher energy intakes and reduced chronic malnutrition of Kenyan children was achieved when water for irrigation available [70].

In the early 1990s, scientists in the United States and Germany noted that better water quality affected other non-water related diseases as well. They found that for every death of typhoid fever averted through water supply improvements, two to three deaths from other diseases such as tuberculosis, pneumonia, and causes of child mortality were also reduced. Today this is known as the Mills-Reincke Phenomenon [34]. For this reason, the potential impact of improved water quality could far exceed current disease-specific statistics and have much farther reaching effect than presently anticipated.

5.4 Water Science for Public Health

5.4.1 Interdisciplinary Collaboration

In developed countries there is an established relationship between the public health practitioners and water and sanitation engineers. This relationship was initially largely driven by the medical community to provide water and sanitation, but today the responsibility lies mostly with engineers. This divergence has created a dissociation of the treatment and provision process, and ultimate health outcome standards. If these health outcomes are considered “benefits”, they are accrued by an alternate party to those responsible for the costs of providing the treated water and infrastructure. Therefore a sort of conflict of interest is created whereby expenditure decisions become difficult and the ultimate goal of health improvements may be lost [22].

In the developing world, the situation is much more severe. As has been shown in the chapters previous, a lack of traction between global leaders, financiers, engineers, and public health practitioners has created a situation where the problems of water and sanitation are evident but, for all the effort, the health outcomes are slow to improve. Only recently have articles been published on the need for intersectoral collaboration in order to change this. Montgomery and Elimelech [41] suggest that increased sustainability of water and sanitation efforts can be achieved when public health and engineering collaborate. Only through addressing environmental effects in combination with social, economic, and demographic factors can the health risks and outcomes be understood and acted upon. This is limited by the extent to which solutions are implemented, used, and maintained [41].

Batterman *et al* [71] suggest that the collaboration must be even larger to include ecologists, anthropologists, economists, and policy makers. They advocate for a more holistic approach that considers both human and ecologic systems and infrastructures, and more of the less immediate factors related to the disease burden. The combination of public health, engineering, social, ecologic, economic, and political domains that affect water related health outcomes are dynamic, interactive, nonlinear, and complex. To limit the study to only the health or engineering aspects ignores a large part of the system and potentially important interactions. Therefore, indicators from these fields should be included in data collection and processing [71].

Long term or more removed factors, although harder to predict, often have significant impact on the system. For example, intergenerational impacts or climate change may be of considerable influence on the relationship between water and health. Unintended consequences may also only appear over longer study periods. Therefore, studying the relationship between water and health may be much more effective using a systems approach where the complex network of interdisciplinary interactions and feedbacks between the two can be monitored over longer periods of time [71]. And, according to Bartram *et al* (2010) the ability of public health professionals to address the immense shifts in political attitude and practices will enable them to champion this collaboration [34].

5.4.2 Regulation

In most countries today, the public health sector's ability to regulate water is primarily through water quality standards. It has no influence on service quality, including coverage, quantity, continuity, and cost, which as seen previously, can have significant health impacts including the deterioration of existing water quality [18].

One way to address this is with health-based quality standards for drinking water treatment. These are suggested by the WHO Guidelines for Drinking Water Quality, but as previously mentioned, are only recommendations and not required standards. Such targets would add a measure of the public health outcomes to the existing chemical and microorganism requirements for water. They would incorporate an assurance of water quantity and reliability to the quality targets. They would also stimulate epidemiologic and service data collection which could improve spending, program, and policy decisions [18]. It is critical though that these targets be reasonable and integrated appropriately as to allow smaller and rural systems the time and resources to meet them [24].

5.5 Implications

The statistics presented previously deliver a gut-wrenching conviction of the need for clean drinking water sources. It is astonishing that the opportunity to prevent so many deaths each year does not receive more attention from the international public health and engineering communities. It will be the greatest shame of our generation if, despite having the technology and the means, we allow so many millions of children to die from diseases the developed world long ago passed by.

Going forward advocacy must be made for water supply interventions as a means of reducing the global burden of disease. Emphasis should be placed primarily on the proximity of a source as well as the volume of water collected. Increasing the level of service improves household water security which will contribute to poverty reduction. It is also important that the continuity of service from a particular supply be ensured. Health gains cannot be maximized by simply providing the infrastructure so emphasis should be placed on the effective use of the available water and the appropriate timing of hygienic practices to reduce the risk of diarrheal diseases.

CHAPTER 6

WATER TREATMENT TECHNOLOGY

As discussed previously in the Health section, significant improvements in health can be made with improvements in the level of service for safe drinking water. One of the conclusions drawn was the importance of proximity to the volume of water collected and the eventual heath outcomes. In this section, information on the treatment of water at the household level to improve health will be developed.

6.1 Household Treatment

6.1.1 Household Treatment versus Source Water Treatment

In order to achieve the greatest health outcomes from drinking water interventions, we must know the best means of implementing them. In the developing world there are largely two sides to this debate: improvement at the source versus improvement at the point-of-use (POU). As discussed previously, in the developing world water is often collected from communal sources that may be a substantial distance from the home and then carried back in some form of a storage container. Many times, even when collection is from an uncontaminated source, microbial contamination is introduced after collection resulting in poor water quality [72].

As early as 1966 there has been recognition that the health outcomes associated with drinking water are largely deteriorated by the requirement of travel from the source to the home and the container used to carry the water [73], [74]. In a study conducted in seven countries, Van Zijl [73] found that jars used for water storage were, without exception, faecally contaminated. Because of this, any reduction in diarrheal disease due to improved water availability was lost. Additionally, the rate of diarrheal disease in areas where a water source was available close to or in the home was always less than the areas in which there was not a piped supply [73]. The studies conducted by Esrey *et al* [55], [56], discussed in section 5.2, concluded that water quality improvements at the source had limited benefits compared to interventions in water quantity, sanitation, and hygiene in the developing world. The potential for uncontaminated water to become polluted when placed in a storage container that had not been cleaned was highlighted [55].

More recent studies have also found water quality deterioration after source collection and some authors argue that the contamination of water post-collection hinders the health benefits of new source installations. In a 2004 meta analysis [75], Wright *et al* concluded that this was in fact the case. They found that in half of the included studies the microbiological quality of water decreased significantly after collection, and in no instances was the quality improved post-collection. Deterioration was even greater where the source water was largely uncontaminated, indicating that in these cases using a protected source may pose greater health risks [75].

However, some authors have argued that repeated exposure to pathogens builds a familial immunity. Under this theory, new source pathogens, which come from other fecal-oral routes such as food or dirty hands, pose a greater health risk and are therefore more important than drinking water in causing disease and drinking water contaminated during collection or transportation does not pose a serious risk of fecal-oral disease [76], [77]. But, these studies do not consider the significant time it takes to build immunity to familial pathogens and the health risks posed to very young children during this time [72]. Trevett *et al* [78] developed a conceptual framework to determine the principal factors which affect the pathogen load in drinking water treated in the home as opposed to the source. They found that water "re-contaminated" post-collection posed a significant risk for disease transmission, especially for infants or the immuno-compromised. They also concluded that the type of container and hand contact with the water were the significant contributors to increased disease risk, but sanitary conditions in the domestic environment, cultural norms and poverty were also linked to the pathogen load [78].

One of the common arguments in support of household treatment and storage is that service can be provided much more quickly and easily than the design, installation, and delivery processes of traditional piped community systems which require a great deal of expertise and training, and may not be supportable in a small community [79]. Promotion of POU treatment allows for immediate benefits until the long-term goal full treatment systems can be achieved.

Today, the ability of simple, acceptable, low-cost water treatment methods at the household level to dramatically improve the microbial quality of stored water and reduce the risks of diarrheal disease and death in populations of all ages is largely the consensus of many researchers as well as the WHO [33], [79-85]. This is not to say that the goal of community wide treatment and provision schemes should be abandoned. But based on the findings, focus for small scale interventions should be placed on the point-of-use or household level, along with promotion of better water handling and storage, rather than improvement at the source in order to minimize the health risks of water-related diseases [72]. Unfortunately, in addition to POU interventions, the metrics used to assess the progress of the MDGs still support improvements at the source. Greater emphasis must be placed on household water treatment and storage if we hope to achieve widespread drinking water access and the outcome of improved health overall.

6.2 Point-of-Use Technologies

A wide variety of POU technologies have been developed for drinking water use in developing world settings. These technologies improve many qualities of the water including microbial quality, chemical quality, turbidity, odor, color, and taste by one or more removal mechanisms which are discussed in further detail below. By improving the water quality, they reduce the health risks of water-related disease. But as vast as their methods of treatment are their configurations, and many technologies require materials or energy sources which are often not readily available or are expensive. Their complexity may also make them inaccessible to many users. Therefore it is essential that the requirements and capabilities of the technology chosen be appropriately matched to the setting in which they will be used.

Unfortunately, little scientific information is available for the efficacy of treatment methods. The ability of some treatment methods to physically remove turbidity and microbes or to inactivate indicator bacteria has been documented. And some methods, such as boiling, solar disinfection, UV lamps, chlorination, and the combination chemical coagulation-filtration and chlorination treatments have also been evaluated for reductions of bacteria, viruses and in some cases protozoa. But the effectiveness of many technologies has not yet been subjected to rigorous study. With the exception of a few, the ability of most technologies to reduce diarrheal disease or other water-related disease morbidity when used in the home has not been studied. This information is essential to determining the appropriate use and performance of a technology but its acceptability by users as well [33].

6.2.1 Treatment Mechanisms

Removal mechanisms used in drinking water technology for developing world settings largely stem from treatment techniques that have been used for thousands of years and reflect their developed world counterparts. Fundamental differences of the application of these technologies in the developing world include the scale, the affordability and availability of materials, and the need to adapt the technologies to the setting and user preferences [33]. These mechanisms can be classified into five categories, but are often combined or separated in other ways:

- Thermal
- Radiation (ultraviolet)
- Filtration
- Chemical
- Membrane

Examples of thermal technologies include boiling, distillation, or prolonged heating. Thermal is often combined with solar radiation in the SODIS method or solar ovens. UV is also used alone in UV radiation lamps. Filtration includes a range of technologies from sand and granular media filters, straining or other fiber filters, ceramic filters, and diatomaceous earth filters. Chemical methods include coagulation-flocculation treatments, adsorption processes, ion exchange, and disinfection with chlorine or other germicides. Membranes may be employed at various scales, from personal straw-like devices, to community systems but are often too costly or complex for developing setting applications.

6.2.2 Turbidity

Turbid source water is often a weakness of household water treatment which may reduce the health benefits. Suspended particles in the water can harbor microbes, and may limit the ability of the treatment mechanism. For example, excessive turbidity may overwhelm the mechanism as in the case of chlorine or physical filtration, or may prevent access to the microbes as in the case of solar disinfection. Therefore, it is often necessary to conduct pretreatment for the purpose of turbidity removal. This may be achieved by settling, cloth straining, or granular media filtering. Depending on the source water quality and nature of turbidity particles, these pretreatment measures may also serve as a major component of the overall treatment [33].

6.2.3 Safe Storage

Storage practices can further affect the health outcomes associated with water through the hygienic practices they foster. An estimated 5.2 billion of the people considered to be using improved water sources are not using safe water because of post-collection recontamination [79]. Numerous studies have documented the increased microbial contamination and reduced microbial quality of water stored in inadequate or vulnerable containers compared to either source waters or improved containers. Many of these studies are summarized in Table 6.1 below. Some studies have also correlated an increased disease risk with the decreased microbial quality and are also summarized in Table 6.1. From the table it can be seen that the decrease in microbial quality is often associated with wide-mouthed or open vessels. In a subsequent study, Mazengia *et al* [84] concluded that water vessels which deterred the use of dipping hands or utensils into the water, by a narrow mouth, tap, etc., also reduced fecal coliform contamination by nearly 50% compared to traditional containers [84]. Wright *et al* found that households that covered their water containers were less often contaminated with fecal coliforms [75]. Covering water containers also protects against contamination by vectors such as mosquitoes, flies, cockroaches, or rodents [79]. Other potential contributors to increased microbial contamination risk include high temperature, prolonged storage times, high levels of airborne particulates, inadequate hand washing, and the use of stored water for food preparation [33]. Therefore, because transportation and storage methods have the potential to so greatly affect the health outcomes of drinking water they must be integrated into any implementation strategy.

Table 6.1 Evidence for Increased Microbial Contamination Infectious Disease Risks from Inadequately Stored Household Water [33]

Study	Location	Storage Vessel	Storage Times	Impact on Microbial Quality	Disease Impact
Spira *et al*, 1980	Rural Bangladesh	Water jars	1-2 days	Increased *V. cholera* presence	Increased (~10-fold higher) cholera rates
Gunn *et al*, 1981	Bahrain	Capped plastic vessels, jars, pitchers	Not reported	*V. cholerae* present in stored but not source water	Uncertain. No significant association with stored water in a case-control study
Deb *et al*, 1982	Calcutta, India	Wide-mouth vs. narrow-necked	Not reported	Not measured	Cholera infections 4-fold higher using wide-mouth storage vessel
Himmad and Dirar, 1982	Khartoum, Sudan	Clay jars ("zeers") in homes, etc.	2 days to 1 month	Increased fecal indicator bacteria over time, in summer and during dust events	Not Measured
Miller, 1984	Rural Egypt	Clay jar ("zir") in homes	1 to 3 days	Algae growth and accumulated sediment	Not detected based on protozoan infection rates
Mascher and Reinthaler, 1987	Abeokuta, Nigeria	Elevated tanks in hospitals	Not reported	Higher plate count bacteria and *E. coli* in tanks than in central supply	Not Measured

Table 6.1 (continued)

Lindskog and Lindskog, 1988	Rural Malawi	Stored household water & other sources	Not reported	Higher fecal coliforms compared to other sources	Not measured
Mascher *et al*, 1988	South Sudan	Not reported	Not reported	Increased fecal bacteria levels	Not Measured
Han *et al*, 1989	Rangoon, Burma	Buckets	Up to 2 days	Higher levels of fecal coliforms than source	Not Measured
Molbak *et al*, 1989	Urban slum and rural villages, Liberia	Large containers, open or closed	"A long time"	Higher levels of enterobacteria in stored than source water	Not Measured
Mertens *et al*, 1990	Kurunegala, Sri Lanka	Earthen pots and others	Not reported	Higher levels of fecal coliforms in stored unboiled water	Not Measured
Verwejj *et al*, 1991	Venda, South Africa	Plastic vessel ("tshigubu")	4 hours	Higher levels of coliforms over time	Measured; no effect
Empereur *et al*, 1992	Rural Africa	Traditional and metal jars	24 hours or more	Higher levels of total and fecal coliforms	Not Measured
Knight *et al*, 1992	Rural Malaysia	Various containers	Not reported	Higher levels of fecal coliforms in unboiled than boiled water	Higher diarrhea risks from water unboiled or stored in wide-necked than narrow-necked containers
Simango *et al*, 1992	Rural Zimbabwe	Covered and uncovered containers	12 hours or more	Higher *E. coli* and Aeromonas levels with storage and use	Not Measured
Swerdlow *et al*, 1992	Trujillo, Peru	Wide-mouth storage containers	Not reported	Higher fecal coliform levels in stored than source waters	Increased cholera risks
VanDerslice and Briscoe, 1993	The Philippines				
Shears *et al*, 1995	Rural Bangladesh	Traditional pots "kulshis"	Not Reported	Increased fecal coliform levels and multiple antibiotic resistance	Increased fecal coliforms and multiply antibiotic resistant flora
Flores-Abuxapqui *et al*., 1995	Merica, Mexico	Not reported	Not reported	Increased bacterial levels in some locales	Not Measured
Swerdlow *et al*, 1997	Malawi, Africa			Increased V. cholerae	Increased cholera risks
Welch *et al*, 2000	Rural Trinidad	Open (drum, barrel, bucket) vs. tank or none	Not reported	Increased fecal bacteria levels in open vessel storage than in tank	Not measured
Dunne *et al*, 2001	Abidjan, Cote d'Ivoire			Increased *E. coli* levels	Not Measured

Optimal choices for storage containers must meet several criteria. Vessels should be portable and easy to use based on their size, shape, weight, and presence of handles. They should be durable and long lasting. They should be coverable with a small tap or spout from which to dispense water sanitarily and a mouth large enough for cleaning and pouring but too small for intrusion of hands or dipping vessels which may introduce contamination. Finally they should be considerate to the user (for example, age or gender) and the user should be educated on how to use the vessel in a sanitary manner and how to clean it regularly in order to prevent biofilm and sediment accumulation. The best vessels hold 10-25 liters of water, are cylindrical or regularly shaped, have a flat bottom, and have one or more handles. They are made of oxidation resistant plastic, have a 6-9 centimeter screw cap, and are fitted with durable, protected and easily closable tap. Finally, they should be affordable, and may need to be subsidized [33].

A further consideration for the selection of a water storage vessel is compatibility with the treatment technology. Some water treatment methods take place within the vessel, such as SODIS, and in these cases the vessel properties must be conducive to the treatment process (i.e. oxidant resistant or stable under UV radiation), not cause any adverse effects, and should be able to protect the quality of the water. In other cases treatment takes place across several containers and these must not only be able to with stand the any chemical treatments but also facilitate transportation of water from one container to the next. Finally treatments which take place outside of the storage container should allow for sanitary delivery of the water to the storage container and protection of the water quality thereafter [33].

6.3 Implementation and User Support

No matter the removal capabilities, no technology can be successful without consideration of the users. Behavioral, educational, cultural, and economic aspects greatly affect the way community or household members use a technology. Generally, users are more immediately concerned with time-savings, privacy, convenience, and prevention of flooding than the health benefits, although these are in the greater interest of the community. Therefore, these perceived needs must be addressed in the technology selection and implementation process [34].

Since the publication of E.F. Schumacher's seminal collection of essays around the idea of "intermediate technology" in 1973, there has been a struggle over the appropriate integration of user preferences in technology in developing settings. The goal focuses on defining what is now known referred to as "appropriate technology": that for which there is a balance between the level of technology required to fully accomplish the task at hand, in this case water treatment, and the level of technology that the user is willing and able to manage [85]. No matter the scale of the intervention, this fit is vital. No technology can be sustainable if the necessary skills, resources, incentives, and support do not exist [22].

6.3.1 Financing

Technology cost and willingness to pay are often limiting factors in technology choice, implementation, operation, and maintenance. Cost can be an initial deterrent for a household or community when considering a water intervention, but often users are already paying for their water in some way, for example from vendors, and they can be transitioned to new treatment and storage practices if the users are aware of the benefit of the substitution. Some intervention schemes have eased the transition by increasing user demand through pricing plans and short-term subsidies or price supports. In order for an intervention to be sustainable, cost recovery must also be achieved. This can be achieved through total, partial, or no cost subsidy. A phased approach has also been used in which subsidies decrease over time or loans must be repaid after an established time period [33].

6.3.2 Marketing and Education

Several programs have been developed for community involvement and participatory education for water and sanitation interventions. These programs use behavioral theory and related sciences to improve implementation practices to ensure that technology use and quality control measures are aligned with the culture, beliefs, and local resources of the users. Doing so improves community involvement and support at all levels and furthers the sustainability of the intervention. Programs commonly include activities surrounding health education, community mobilization, social marketing, motivational interviewing, focus groups, and other techniques to modify behaviors, facilitate learning and elicit participation [33].

One of the most successful and widely used of these programs, known by the acronym PHAST (Participatory Hygiene And Sanitation Transformation) was developed by the WHO [86]. This program elicits changes in sanitation and hygiene behavior through promotion of health education among all the members of a community or society. It fosters improvement in the community through participation, recognition and encouragement of self-awareness and innate abilities, encouragement of group participation at the grassroots level, promotion of concept-based learning as a group process and linking conceptual learning to group decision-making about solutions and plans of action. It also supports both material and financial investment decisions from within the community [33].

Another program, called the MANAGE dissemination system, has been used successfully in Africa, the Indo-Asian region, and Latin America. This system was developed by the International Water and Sanitation Centre as a way to facilitate support agencies in developing community interest and ability to take responsibility for their water supplies. The program stems from information sharing of multi-institutional learning approaches, development training methods, and tools to facilitate community participation between intervention locations [33].

Another method of improving the sustainability of water interventions is social marketing. This activity is used to gain acceptance and support for proper use of the technology and supporting hygienic practices, but is dependent the marketable commodities of the technology such as the disinfectant used or the storage container. For example, chlorine use is often controversial or abandoned by users because of taste issues or fear of disinfection byproducts, so social marketing is important to encourage users to buy and use chlorine solution in areas where this type of disinfection is used [33]. But the tone of the messages used for social marketing may have a substantial impact on their success. Advertising agencies have known for years that emotional messages change behaviors more effectively than cognitive statements. For example, "clean hands feel good" is more effective than "dirty hands cause disease". Therefore, promotional messages should focus on clarity, taste, affordability, and ease of use and implementers must realize that health improvement is not always the greatest motivation for behavior change [34], [79].

6.3.3 Continued External Support

A common misconception of community water supplies in rural areas of developing countries is that after a short period of time, users benefitting from the new technology will be able to manage the system themselves. It is more often the case that external support may be needed for years before the capacity to maintain the system is established within the community [1]. Without continued external support, the lifespan of a technology may only be a few years [22].

6.4 Scaling

One of the major debates in achieving the MDG for water has centered on how small household or community systems can be "scaled up". Household water treatment and storage (HWTS) is a promising approach, but cannot be successful in achieving the MDG unless interventions can be implemented at scale. Yet the question, "if it can work at a small scale, how can it be made to work at a large scale?" may not sufficiently address the problem.

The obvious implication of the term "scaling up" is increased coverage. Most definitions of the term include descriptions of reaching more people over a greater geographic area. This means that a greater percentage of the people who need coverage will receive it. In fact, this is the metric by which the MDG measures success (albeit decrease of the lack of coverage). But, the presence of a HWTS intervention alone does not guarantee the outcome of improved global access and health; thus coverage must only be one aspect of the definition.

In order to achieve the greater results intended from “scaled up” applications, they must also be implemented correctly. This means that they must also address their target audience and they must be embraced and routinely used correctly by their users. Thus scaling depends not only on the ability of the intervention to reach the population but the extent to which it is adopted and used consistently. In other words, scaling up HWTS must consider both supply (increasing coverage) and demand (promoting use) [81].

Others are skeptical as to whether scaling is even an appropriate approach. Underlying much of the concern is the fear that funding for water, sanitation, and hygiene is a zero-sum game. That is, scaling of water interventions must necessarily detract resources from other interventions. This idea likely stems from the experience of the water and sanitation sector in competition for attention with causes like HIV/AIDS and Malaria [81]. Another concern is that focus on scaling ignores the infrastructural and institutional weakness that are often associated with poor coverage and that, instead, focus should be placed on progress as a whole [18]. In terms of resource diversion, studies have shown that there is little evidence to support this concern, and that in the event it is small. Schmidt and Cairncross [87] argued that much of the cost of HWTS interventions is often borne by the householder and it is unlikely that resources that would have been used otherwise are being diverted. They argue that governments may attempt to highlight HWTS in order to divert attention away from failing public water supplies [87]. This may actually have the opposite effect, and supports the concern that scaling programs may overlook the greater underlying problem.

PART 2

PROJECT SCOPE

CHAPTER 7

PROJECT DEFINITION

7.1 Areas of Focus

From the information presented previously, several conclusions are drawn upon which the following is presented. The first of these is the clear written and actual priority of water and sanitation. In other words, it is clear in terms of the need of water for life that clean water is necessary. In terms of health, water-related illnesses contribute to a large percentage of the global disease burden, especially among young children. It is also clear that through the presence of statements to this point in international agreements, water has proven to be a main concern on the global development front as well. The recognition of the need and intent to provide clean drinking water to all is evident. What are lacking are appropriately directed actions which will achieve this priority for all.

The second conclusion is just that; despite the recognition of the problem, and even a significant amount of funding and effort put forward, efficiency towards the MDG is low. Misdirected funding, poor implementation strategies, and poor standards of success are the culprit and have resulted in progress that is significant but slow and a fraction of what it could be given the technology and resources available. Additionally, focus has been placed on global progress as a whole which has left Sub-Saharan Africa lagging in coverage.

Third, there are certain factors which have repeatedly presented themselves as hurdles to progress. Among these are financing, operations and maintenance, and intersectoral collaboration. Accurate estimates of cost, including the delayed or repeated costs of operations and maintenance, and full cost-recovery prevent interventions from being sustainable beyond their initial installation and hinder future interventions. Poor operations and maintenance habits can add to water-related health risks. Finally, lack of collaboration and information sharing between engineers and public health practitioners specifically leads to advanced technologies which are not applicable in the field due to user acceptability issues or materials and energy source availability, and a lack of data collected at the point of application from which better targeted efforts can be determined.

Finally, while community scale water treatment facilities have done well to increase coverage in many parts of the world, this may not be the best approach in the remaining regions which are struggling to extend coverage. Household based treatment and storage interventions utilized at the point of use have significant potential to provide safe drinking water to these areas. These interventions use a variety of treatment mechanisms ranging from extremely basic to very complex. It is also important that along with the intervention installation users receive detailed training on the correct and continued use of the device, education on the need for clean water and hygiene, and extended support for maintenance and cost-recovery.

7.2 Technology Selection Guide

The following technology selection guide produced as a result of this research attempts provide assistance in technology selection by addressing the immediate issue of water quality for the sake of health benefits, while also considering the context of the installation, the user preferences, the level of expertise of the implementers, the cost, operations and maintenance requirements, and common areas of failure.

Many other resource guides are available for the installation and use of HWTS technologies. This technology selection guide is unique in several key respects. First, it addresses the focus areas explained previously in one document. The information contained in the document is extracted from many sources which include resources produced by the agency which developed the technology, organizations which implement the technology, and scientific studies. Often these discuss only certain aspects of the technology deployment or are not forthcoming about the costs, level of maintenance required, or limitations of the technology. As a result, extensive research must be done for a well informed comparison of candidate technologies. The technology selection guide will compile this information into one document.

The selection guide will also serve as a translation between the developers of the treatment technology and those who implement it in developing countries. It will be marketed toward a non-technical audience, but draw on the expertise of engineers and improve existing implementation practices. It highlights the technical aspects of the treatment mechanisms in layman's terms so that this information can be properly considered during application of the technology, and with the goal of setting-minded modification to the technology without losing performance. This information will also be beneficial in understanding appropriate and inappropriate technology for a given application based on the capabilities of the technology and the water treatment needs in the setting.

The guide may also be beneficial to engineers in that it will consider sociocultural aspects of technology use. Often it is the implementers who are most aware of how greatly user preferences and cultural practices affect the dissemination and sustainability of HWTS technology and because they are not often engineers, this information is lacking in engineering journals. These "softer" aspects of application are important considerations for engineers developing new technologies and those which take these aspects into consideration may be much more successful.

7.2.1 Format of the Document

The technology selection guide is written in a way that provides a foundation for further publication. The guide is organized in a sort of section and chapter manner. The sections of the document each highlight a treatment mechanism, which include thermal, radiation, media filtration, chemical, and membrane. The sections are lead by an introduction which explains the general concept of that mechanism, followed by "chapters" which discuss a particular technology that treats water using that particular mechanism. The document is structured so as to allow new descriptions of technologies to be added seamlessly as new chapters in their respective sections. The technologies included at this point were chosen based on several factors: they must be applicable in Africa, be applicable in rural settings which have materials or energy source restraints, be low-cost, and be applicable at the household level.

APPENDIX A

TECHNOLOGY SELECTION GUIDE DOCUMENT

The Technology Selection Guide is intended to be a stand alone document. It should read as a book, with each two pages here forming the front and back sides of one book page. The first two pages form the front and back of the cover of the book, and the remainder of the document follows accordingly. It begins on the following page.

Water Treatment Technology Selection Guide

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Household Water Treatment and Storage Technology Selection Guide

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Contents

Introduction

Water is a sine qua non of human life. It is well known that a person may live weeks or even months without food, but only a few days without water. When water contains pathogens or other contaminants a new set of concerns arises. An estimated 1 billion people in the world do not have access to an improved source of drinking water. 5.2 billion of those who do still drink unsafe water due to post-collection contamination. Diarrheal diseases, often caused by or contributed to by poor quality water, are among the leading causes of death and disability in the world.

It is devastating that in this modern era there are still so many who do not have this most basic of needs. This problem has been recognized for more than thirty years and a great deal of progress has been made in that time. However there is still a great deal of work to be done. To reach those who remain unserved and to ensure recontamination no longer occurs, new approaches must be developed. In the past the greatest hurdles have included financing and cost recovery, planning for and continued operations and maintenance, and a lack collaboration from professionals working different aspects of the problem.

This guide addresses those hurdles. It seeks to provide a total solution; one that will allow for the selection of a technology which will address the immediate issue of water quality for the sake of health benefits, while also considering the context of the installation, the user preferences, the level of expertise of the implementers, the cost, operations and maintenance requirements, and common areas of failure. It allows for technologies to be compared so that the most appropriate technology is selected for the application. The guide will also serve as a translation between the developers of the treatment technology and those who implement it in developing countries.

Other technology guides such as this one do exist. However, this guide is unique in one key respect. It addresses most aspects of technology implementation at once. The information contained in the document is extracted from many sources which include resources produced by the agency which developed the technology, organizations which implement the technology, and scientific studies. Often these discuss only certain aspects of the technology deployment or are not forthcoming about the costs, level of maintenance required, or limitations of the technology. As a result, extensive research must be done for a well informed comparison of candidate technologies. The technology selection guide will compile this information into one document.

How to Use This Guide

Point-of-use water treatment technologies are simple, acceptable, low-cost ways to dramatically improve the microbial quality of stored water and reduce the risks of diarrheal disease and death in populations of all ages. These technologies allow clean water to be provided more quickly and easily than traditional treatment systems. A wide variety of technologies have been developed to improve many qualities of the water including microbial quality, chemical quality, turbidity, odor, color, and taste by one or more removal mechanism. However, it is important to match the technology to the water treatment needs of the community.

No matter the removal capabilities, however, no technology can be successful without consideration of the users. Behavioral, educational, cultural, and economic aspects greatly affect the way community or household members use a technology. Generally, users are more immediately concerned with time-savings, privacy, convenience, and prevention of flooding than the health benefits, although these are in the greater interest of the community. Therefore, these perceived needs must be addressed in the technology selection and implementation process as well.

Furthermore, the sustainability of a technology is dependent upon adequate financing, and balance of community and external support. Technology cost and willingness to pay are often limiting factors in technology choice, implementation, operation, and maintenance. Education and training for the use of the technology are important to ensure that technology use and quality control measures are aligned with the culture, beliefs, and local resources of the users. External support may be needed for years before the capacity to maintain the system is established within the community.

It is important to consider all of these factors when undertaking technology implementation. This guide is intended to aid in the implementation of household water treatment technologies in developing world by presenting many of the necessary considerations in one place and allowing for a comparison of the technologies based upon the needs of the community. The guide also presents the technical aspects of the technologies' treatment mechanisms, which are often overlooked or misunderstood, so that these may be correctly established and modified appropriately to fit the situation.

In the past, engineers and practitioners have worked on opposite ends of this global problem, not always understanding fully the perspective of one another. By combining the necessary considerations from each side, this document aims to facilitate intersectoral collaboration between the two and improve the rate of progress towards access to clean, safe drinking for all.

How it works

This section describes the mechanism or mechanisms by which the technology works. It is meant to give an easy-to-follow explanation of the science behind the technology so that users and implementers understand and maintain it. Callout sections give further detail about the mechanisms.

When To/Not to Use It

This section highlights the strengths and weaknesses of the technology to ensure that it is used appropriately.

Materials and Installation

This section lays out everything necessary for proper construction and/or installation of the technology. Some technologies function differently depending on the materials used. Other technologies require very specific installation or preparation in order to function properly. Therefore, it is important to understand the correct procedures.

Cost

The cost of each technology is represented by one, two, or three dollar signs ($) representing low to high cost respectively. Explanations are also given where cost varies from one application to the next or over time.

Training

Training is an important step to ensuring that a technology is used properly. This section lays out the roles of the users, community, and external support members for education and training which are characterized by the amount of skill required for each role.

Use

This section lays out the correct procedure for regular use of the technology. It is important that these procedures are followed closely to ensure the both the longevity of the technology and the safety of the water it produces. Where necessary, technical callouts are provided.

Operations and Maintenance

Operations and maintenance is often given little if any forethought but is one of the most critical aspects of ensuring the sustainability of a technology. This section provides the necessary tasks and materials for maintenance at different intervals throughout the technology's lifespan.

Removal

The charts in this section are segments from the technology comparison charts at the beginning of this guide. They characterize the removal capabilities of the technology for different contaminants.

Longevity and Scalability

This section discusses the lifespan of the technology and the possibility of its use to be scaled up. Household water treatment and storage is a promising approach, but cannot be successful in achieving the Millennium Development Goals unless interventions can be implemented at scale.

Limitations and Potential Problems

These are special considerations and concerns for the use of the technology.

For Training Material and More Information

Websites or other materials are listed for further reference.

Causes of Common Water Related Illnesses

	Agent	Disease
Bacteria	Aeromonas	Diarrhea
	Campylobacter jejuni	Campylobacter Enteritis
	Chlamydia trachomatis	Trachoma
	Pathogenic E. Coli	Diarrhea
	Salmonella typhii	Typhoid and Paratyphoid Fevers
	Shigella	Dysentery
	Vibrio cholerae	Cholera
	Yersinia enterocolitica	Diarrhea
Virus	Adenovirus	Gastroenteritis
	Dengue	Dengue fever
	Enterovirus	Gastrointestinal Infection, Pink eye, Foot and Mouth Disease,
	Flavivirus	Japanese Encephalitis
	Hepatitis A virus	Hepatitis A
	Norwalk and Norwalk-like viruses	Diarrhea, Gastroenteritis
	Polio virus	Gastrointestinal Infection, Polio
	Rotavirus	Diarrhea
Protozoa	Cryptosporidium	Diarrhea
	Entamoeba hystolitica	Dysentery
	Giardia	Giardia
	Plasmodium	Malaria
Helminth	Ascaris lumbricoices	Ascariasis
	Dracunculus medinensis	Dracunculiasis
	Wuchereria bancrofti, Brugia malayi	Lymphatic filariasis
	Ancylostoma duodenale, Necator americanus	Hookworm
	Onchocerca vulvus	Onchocerciasis
	Schistosoma haematobium, S. japonicum, S. mansoni	Schistosomiasis
	Trichuris trichiura	Trichuriasis

Technology Comparison Chart

		Bacteria	Virus	Protozoa	Helminth	Algae
Distillation	Lab	**High** (Hanson 2004, National Academy of Sciences, CDC 2008)	**High** (National Academy of Sciences, CDC 2008)	**High** (National Academy of Sciences, CDC 2008)	**High** (Skinner & Shaw 1998, CAWST)	**High** (National Academy of Sciences)
	Field	-	-	**High** Including C. parvum (Foster et al)	-	-
Solar Disinfection	Lab	**Moderate/High** (McGuigan 1998, Berney 2006, Reed 1997, Wegelin 1994)	**Moderate/ High** (Fujioka 2002)	**High** (Gaafar 2007, Lonnen 2005) Including C. parvum (Mendez-Hermida et al 2005, King 2008)	-	**None** (National Academy of Sciences)
	Field	**High** (Sobsey 2008, Conroy 1999)	**High** (Sobsey 2008)	-	-	-
BioSand Filtration	Lab	**High** (Baumgartner et al 2007, Sobsey 2008, Stauber et al 2006)	**Moderate** (Elliott et al 2008, Sobsey 2008, Lantagne 2007)	**High** (Palmateer et al 1999, Sobsey 2008)	**High** (Skinner & Shaw 1998)	**None** (National Academy of Sciences)
	Field	**High** (Duke et al 2006, Stauber et al 2006)	-	-	-	-

Technology Comparison Chart

		Fe/Mn	Fl	As	Salt	Odor & Taste
Distillation	Lab	-	**High** (Hanson 2004, National Academy of Sciences)	**High** (National Academy of Sciences, National Sanitation Foundation Standard 62, CDC 2008)	**High** (National Academy of Sciences, Hanson 2004, CDC 2008)	-
	Field	-	**Some** (Foster et al, Hanson 2004)	**High** (Foster et al)	**High** (Foster et al, Hanson 2004)	-
Solar Disinfection	Lab	**None** (National Academy of Sciences)	**None** (National Academy of Sciences)	**None** (National Academy of Sciences)	**None** (Skinner & Shaw 1998)	**None** (Skinner & Shaw 1998)
	Field	-	-	-	-	-
BioSand Filtration	Lab	-	**None** (Skinner & Shaw 1998)	**Removal can be achieved with modifi-cations**	**None** (National Academy of Sciences)	**Moderate†** (National Academy of Sciences)
	Field	-	-	-	-	-

Technology Comparison Chart

		NOM	Turbidity	Residual Treatment	Acceptable	Diarrheal Morbidity Reduction	Scalable ?
Distillation	Lab	-	**High** (Flendrig 2009)	**No**	-	-	**Yes** (Malik et al 1982)
	Field	-	-		**Yes**	**Yes**	
Solar Disinfection	Lab	**None** (Skinner & Shaw 1998)	**None**	**No**	-	-	**No**
	Field	-			**Yes** (Conroy et al 1999)	**Moderate/ High** (Conroy et al 1996, Reller et al 2003, Graf et al2010, Rose et al 2006)	
Biosand Filtration	Lab	**Mod/ High** (Skinner & Shaw 1998)	**High** (Jenkins et al 2009)	**No**	-	-	**Yes**
	Field	-	**Moderate/ High** (Baker et al 2006, Vanderzwaag 2009)		**Yes** (Duke et al 2006, Liang et al 2007)	**Some** (Stauber and Sobsey 2006)	

Technology Comparison Chart

		Bacteria	Virus	Protozoa	Helminth	Algae
PUR Packets	Lab	**High** (Souter et al 2003, P&G)	**High** (Souter et al 2003, P&G)	**High** (Souter et al 2003, CAWST 2009) Removal is moderate to high for C. parvum (WHO GDWQ 2008, P&G, Souter et al 2003)	**High** (CAWST 2009)	-
	Field	**High** Including cyanobacteria (Souter et al 2003, Allen et al 2004)	**High** (Souter et al 2003, Le et al 2003)	**High** (Souter et al 2003) Removal is moderate for C. parvum (Crump et al 2004)	-	-
LifeStraw Family	Lab	**High** Meets EPA 6-4-3 Standard (Clasen 2009, Vestergaard Frandsen, Intertek Vietnam, CDC 2008)	**High** Meets EPA 6-4-3 Standard (Clasen 2009, Vestergaard Frandsen, Intertek Vietnam, CDC 2008)	**High** Meets EPA 6-4-3 Standard (Clasen 2009, Vestergaard Frandsen, Intertek Vietnam)	**High** (Sobsey 2002, Vestsergaard Frandsen)	-
	Field	**High** (Boisson 2010, CDC)	-	-	-	-

Technology Comparison Chart

		Fe/Mn	Fl	As	Salt	Odor & Taste
PUR Packets	Lab	-	-	**High** (Souter et al 2003, P&G)	-	-
	Field	-	-	**High** (Souter et al 2003, Norton et al 2003a)	-	**Moderate†** (CAWST 2009)
LifeStraw Family	Lab	-	-	**None** (CAWST 2009)	-	**Some** (CAWST 2009)
	Field	-	-	-	-	-

Technology Comparison Chart

		NOM	Turbidity	Risdual Treatment	Acceptable	Diarrheal Morbidity Reduction	Scalable?
PUR Packets	Lab	**High** (P&G)	**High** (CAWST 2009)	**Yes** (Souter et al 2003, McLennan et al 2009)	-	-	**No** (Luby et al 2006)
	Field	-	**High** (Norton et al 2003b, P&G, Crump et al 2004)	**Yes** (Norton et al 2003b, Le et al 2003, Crump et al 2004, Doocy et al 2006)	**Somewhat** (Doocy et al 2006, Luby et al 2008)	**Moderate to High** (P&G, Crump et al 2005, Doocy et al 2006, Luby et al 2006, Reller et al 2003)	
LifeStraw Family	Lab	-	**High** (Vestergaard Frandsen)	**No** (Clasen 2009)	-	-	**No**
	Field	-	**High** (Institute of Technology of Cambodia)		**Yes** (Elsanousi et al 2009, Boisson et al 2010, Institute of Technology of Cambodia, Vestergaard Frandsen with USAID)	**High** (Boisson et al 2009, Vestergaard Frandsen with Michigan State University, University of California at Berkely, University of Michigan, and London School of Hygiene and Tropical Medicine)	

Thermal

Technologies which use thermal treatment utilize pathogens' inability to withstand high temperatures for long periods of time. The time and temperature required, however, are individual to the pathogen. In the developing world, heat treatment is most often achieved either by boiling or using the sun's thermal energy to heat water for a prolonged period.

Boiling is the most basic heat inactivation method and has long been used to disinfect water. Temperatures reaching 212°F, the boiling point of water at sea level, are sufficient to kill most pathogens in a short amount of time. However, the energy necessary to heat water to this point on a daily basis, whether from burning fuel or electricity, is prohibitively expensive in many parts of the developing world. In addition, boiling does not affect turbidity or most other organic or chemical contaminants in the water.

Solar distillation harnesses the infrared energy of the sun to heat purify water in much the same way as the natural water cycle. In this method, water is placed in a closed container, called a still, and the pure evaporate is collected from a condensing surface. Distillation is capable of removing salts, heavy metals and pathogens. However, it is limited by the intensity of solar radiation available and daily outputs may be low if the still is not large enough.

The SODIS method, which primarily uses radiation treatment, also uses heat as a secondary mechanism. Solar ovens use a similar approach by placing a dark or reflective open container of water inside a box designed to capture the sun's heat. However, the amount of time required for the water to reach inactivation temperatures is quite long and may be a concern for user acceptability.

Distillation

Distillation has been used as a form of water treatment for over 2000 years. However, in the past it was more often used to produce salt than clean water. Today the reverse is also true: in many parts of the world water is desalinated to produce drinking water. Distillation uses the same process as used by nature to produce rain: water evaporates as it is heated and condenses as it cools. Distillation can be achieved in a number of ways but the content of this section will focus on solar distillation. It is important to note, however, that it is the heat from the sun, not the ultraviolet radiation, which treats the water in this technology and it is therefore a thermal process.

How it works

Rather than disinfecting or removing contaminants, distillation removes purified water from the contaminated source water. In this process source water is heated until pure water evaporates, leaving microbes and contaminants behind. As the water vapor passes through the air it cools. It is intercepted by an angled surface on which it condenses, and then runs down the surface to be collected. The efficiency of this process relies on several factors, including the depth of the source water, the effectiveness of the heating source, the difference between the water and the ambient air temperatures, the material and insulation of the source water basin, and the orientation of the condensing surface [1].

Often, distillation is done in a solar still that uses thermal energy from the sun to heat a covered pool of water. In a passive solar still the sun is the only source of heat for the water, while in an active still the water is also heated by a secondary method. Active stills may heat the water simultaneously with the sun or receive hot water from another source raising the temperature in the source water basin from 20-50°C to 70-80°C. For greater efficiency, some stills are operated at night to take advantage of the cooler air temperature [1].

Another standard method for heating the source water is boiling. However, a fuel source is needed to boil water. It is estimated that 1kg of wood is needed to boil 1 liter of water. In many areas of the world, especially in parts of Sub-Saharan Africa, biomass fuels like wood or fossil fuels are unavailable or highly expensive making boiling unavailable [2]. Dependence on wood for fuel can also lead to deforestation and contributes to poor health through indoor air pollution. Therefore boiling is not often an optimal heating method.

Let's Get Technical: Energy Requirements

The latent heat of vaporization is the amount of energy required to evaporate water. The latent heat of vaporization for water is 2,260 kJ/kg which means that it theoretically takes this much energy to evaporate one liter of water. However, the efficiency of the heating method is often less than 100% (see below), and therefore a greater amount of energy would actually be required. On the other hand, only o.2kJ/kg of energy is required to pump water 20m vertically, and therefore distillation is often only appropriate where a source of groundwater is unavailable [3].

In a solar still, the material covering the pool of water is often glass. The glass allows short wave radiation from the sun to pass into the still. As the still absorbs the radiation it heats up, warming the water in the pool and raising the moisture content of the air inside the sill. Often the bottom of the base of the pool is blackened to enhance absorption. The blackened base also radiates long wave infrared radiation which is trapped inside the still by the glass cover producing a greenhouse effect. Water evaporates from the basin and collects on the glass which is inclined so that condensed water runs down the glass, into a collection trough, and then to a storage container outside the still. Figure 1 below gives a basic schematic [4]. It is important that the entire still is water tight and air tight to ensure efficiency [5].

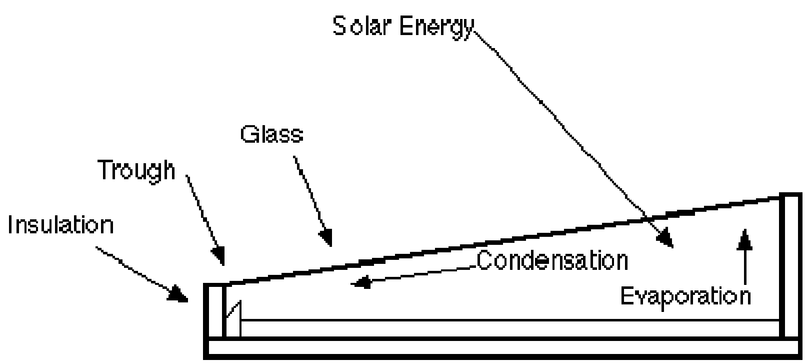


Figure 1 A Simple Solar Still [4]

When to use it

- When solar radiation is reliably high and unobstructed by clouds year round
- When source water is brackish or saline

When not to use it

- When a sufficient ground water supply is available
- When the volume of available water is limited due to the need for excess water for flushing of the still.
- When there is not space for a large still or when there is a high volume requirement.

User Acceptability

Pros

- Taste is not affected
- No moving parts

Cons

- Very low volume produced

Let's Get Technical: Boiling and pH

When water is distilled by boiling, steam is released. As the steam passes through the air, carbon dioxide is absorbed leaving the resulting distilled water with a slightly acidic pH. This is said to leave the water with a "flat" taste. Distillation by evaporation, however, does not affect the pH of the water and therefore there is less resistance to taste among users [4, 6].

Materials and Installation

Materials selection for a solar still is very influential to its efficiency. The still cover must allow solar energy to pass through. Glass and plastic are the best choices. Glass is a longer lasting option but may be prohibitively expensive. Cement, plastic, or aluminum may be used for the basin. Cement is a better insulator, but cement basins may be difficult to transport if not poured on site. Plastic or aluminum basins should be insulated for efficiency [3].

The construction of a solar still can be relatively simple. A basic design may follow the schematic shown above. The cover should be securely sealed to the basin to prevent heat and moisture from escaping. Prefabricated stills are also available online.

Several modifications may be made to the design to improve the efficiency of the still. Hundreds of scientific publications examine the effects of different still materials, insulation, reflectors, still configurations, compound systems, active heat sources and heat recovery, and wicking materials. For example, reflective materials can be used to line the walls of the still to enhance heating. Heating elements, or heat exchange with common appliances, may also be used. These could include generators or refrigerating units already available in the community. Stills can also be used in combination. Stacked stills use the underside of the basin of the top still as the condensing surface for the bottom still, utilizing the heat given off by the condensing vapor to heat the upper still. However, the basic single basin still (shown in Figures 1 and 2) is still the only design proven in the field [3].

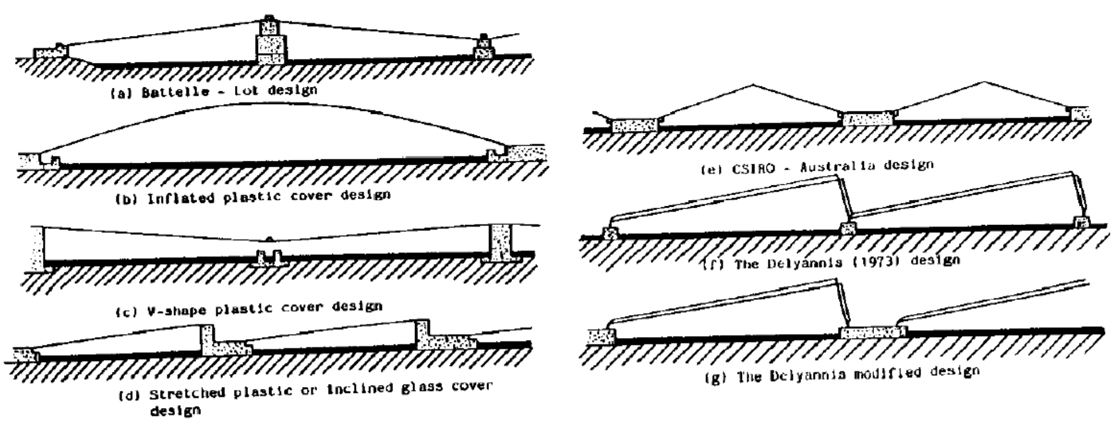


Figure 2 Simple Types of Solar Stills [5]

Cost: $

Solar stills are one of the least expensive rural water treatment options because there are very few materials, no chemical costs, no moving parts to replace, and no infrastructure to build. The cost of a still will vary based on the chosen configuration but is largely based upon the size of the still, transportation of materials, labor for construction, and any land cost.

Training

Actors	Roles	Skills Required
Family member	Fill the still, collect water, clean utensils, flush the still	☺
Local craftsman	Make any necessary repairs to the still	
External Support	Construct the still, train family members on use of the still, monitor continued proper use	

☺ Simple, often requires awareness raising or training

 Level of technical skill required

Use

Use of a solar still is relatively simple. The still should be filled at least once a day, depending on its production capabilities, in the morning or evening. Splashing of untreated source water onto the condensing surface of the still when the still is being filled may introduce contamination into the distillate. For this reason, it is best to fill the still in the morning or evening before the day's water has been distilled. At this time the distilled water from the previous day can be collected from the storage container. Collecting in the morning also allows the still to take advantage of the greater differences between the water temperature and cooler night air. The standard production capacity of solar still depends on the surface area of the basin but is usually between 5 and 11 L/ m^2•day [5].

Let's Get Technical: Output

There are several aspects which affect the efficiency of a solar still. The most important, however, is the intensity of solar irradiation incident on the still. A good idea of the output of a still can be calculated from the basic equation below:

$$M_e = Q_e/L$$

Where Q_e (J/m^2•day) is the amount of energy utilized in vaporizing water in the still daily output of the still in liters per day, L (J/kg) is the latent heat of vaporization of water (2,260 kJ/kg), and M_e (kg/m^2) is the daily output of distilled water.

The efficiency η is given by:

$$\eta = \frac{Q_e}{Q_t}$$

where Q_t (J/m^2•day) is the amount of solar energy incident on the glass cover of the still [5]. However, the efficiency of a typical basin still is usually not greater than 60% [7].

Operations and Maintenance

Activity and Frequency	Materials and Spare Parts	Tools and Equipment
Daily		
- Flush the still	Bucket, water	
Occasionally		
- Make necessary repairs, remove scaling	Varies	Varies

Flushing the still is necessary to prevent the buildup of salts and contaminants in the still. Each day when the still is filled, three times the average daily production volume should be added. In other words, if the still produces 2 liters per day, 6 should be added to the still each time. The additional water will flow out the overflow port. This water should not be used for consumption but, if the still is cleaned daily, the level of contamination should be low enough that the water can be used in other ways, such as irrigation [4]. The storage container should also be cleaned regularly to prevent recontamination of the treated water. Stills that are properly maintained have been known to last more than 40 years [4].

Removal

	Bacteria	Virus	Protozoa	Helminths	Algae
Lab	**High** (Hanson 2004, National Academy of Sciences, CAWST)	**High** (National Academy of Sciences, CAWST)	**High** (National Academy of Sciences, CAWST)	**High** (Skinner & Shaw 1998, CAWST)	**High** (National Academy of Sciences)
Field	-	-	**High** Including C. parvum (Foster et al)	-	-

	Fl	As	Salt	Turbidity
Lab	**High** (Hanson 2004, National Academy of Sciences)	**High** (National Academy of Sciences, National Sanitation Foundation Standard 62)	**High** (National Academy of Sciences, Hanson 2004)	**High** (Flendrig 2009)
Field	**Some** (Foster et al, Hanson 2004)	**High** (Foster et al)	**High** (Foster et al, Hanson 2004)	-

Sources: [8], [9], [10], [7], [11]

Longevity and Scalability

Distillation can be scaled up indefinitely with the size of the still. The first conventional distillation plant was constructed for a mining community in Chile in 1872. This plant was 4,700 square meters in size and produced more than 23,000 liters of water a day [4]. Modern commercial stills as large as 10,000 square meters have been used for more than fifty years, supplying entire communities around the world [5].

Limitations and Potential Problems

Distilled water contains no minerals and can cause nutritional problems if it is the only source of drinking water or mineral in the diet [9].

For Training Material and More Information:

Malik, M.A.S., et al., *Solar Distillation*. 1982, New York: Pergamon Press.

http://www.solaqua.com/index.html

References:

1. Sampathkumar, K., et al., *Active solar distillation-A detailed review*. Renewable & Sustainable Energy Reviews, 2010. **14**(6): p. 1503-1526.
2. Sobsey, M.D., *Managing Water in the Home: Accelerated Health Gains from Improved Water Supply*. 2002, World Health Organization: Geneva.
3. Practical Action. *Solar Distillation*. 2011 [cited 2011 May 4]; Available from: http://www.itdg.org.pe/fichastecnicas/pdf/solar_distillation.pdf.
4. Solaqua. *Solar Still Basics*. 2008 [cited 2011 May 7]; Available from: http://www.solaqua.com/solstilbas.html.
5. Malik, M.A.S., et al., *Solar Distillation*. 1982, New York: Pergamon Press.
6. Gurr, E., *Effect of Heat on the pH of Water and Aqueous Dye Solutions*. Nature, 1962. **195**: p. 1199-1200.
7. Foster, R.E., W. Amos, and S. Eby. *Ten Years of Solar Distillation Application Along the U.S.-Mexico Border*. Available from: http://www.sunstar-solutions.com/10yrsStillsPaper.PDF.
8. Hanson, A., et al., *Distillate water quality of a single-basin solar still: laboratory and field studies*. Solar Energy, 2004. **76**(5): p. 635-645.
9. National Academy of Sciences. *Safe Drinking Water is Essential: Technologies*. 2008 [cited 2011 May 9]; Available from: http://drinking-water.org/flash/en/water.html?_3_00_00.
10. Flendrig, L.M., et al., *Low cost thermoformed solar still water purifier for D&E countries*. Physics and Chemistry of the Earth, 2009. **34**(1-2): p. 50-54.
11. CAWST. *Household Water Treatment and Safe Storage Fact Sheet: Solar Distillation*. 2009; Available from: http://www.cawst.org/en/resources/pubs/category/25-fact-sheets-academic.

Radiation

Radiation treatment technologies used in developing world applications primarily use solar radiation. These are generally low cost and simple, and are applicable in even the most remote settings because they do not require energy or chemicals, and in most cases they do not require replacement parts.

In these technologies, it is the ultraviolet radiation specifically that is the effective treatment mechanism. As with humans, ultraviolet radiation has damaging effects for microbes. Ultraviolet radiation is absorbed by the microbe's DNA causing damage that impedes the transcription and replication processes. This interruption in basic cell functions has proven effective in the reduction of viable bacteria and viruses as well as protozoa. However, ultraviolet radiation has no effect on chemical or organic material and thus does not treat any contamination other than microbial. Turbidity is especially a problem for solar radiation because the suspended particles prevent penetration of the ultraviolet radiation into the water.

Technologies in this category include solar disinfection in plastic bottles (known as SODIS), and treatment with ultraviolet lamps. Both use the same principles and process, but treatment with a lamp is more common in developed world settings. The limitations of this mechanism are many however. Use of ultraviolet radiation is limited by the depth of the water, the type of microbe, the initial water quality, the exposure time, the solar irradiance, and vessel material and orientation. Limited studies have been conducted to determine the diarrheal disease reduction potential of solar methods, but have demonstrated moderate to high success.

A more advanced application of this mechanism is the Naïade by Dutch company, Nedap. The Naïade uses two filters of 10 and 25 μm and a solar panel to power a 20 watt ultraviolet lamp. Nedap claims that the product kills at least 95% of bacteria, viruses, and protozoa and can produce nearly 800 gallons of water per day. Very little maintenance is required to clean the filters and replace the lamp as needed, but the unit cost is US$5,000.

Solar Disinfection (SODIS)

The SODIS method was first introduced in the 1980s as an oral rehydration tool in Lebanon. It was later adapted by the Swiss Federal Institute of Water Science and Technology (EAWAG) as a water treatment method. After extensive research into its feasibility and the disinfection mechanisms, SODIS has been developed as a simple, low cost, and sustainable method of treating drinking water at the household level. It is ideal for low volume applications where the microbial quality of the water is a concern. SODIS uses solar energy to inactivate pathogens in the water which cause water-related illness thereby improving the quality of the water. Reductions in diarrheal disease morbidity of 30-80% have been achieved. The World Health Organization, UNICEF, and the Red Cross have each recommended SODIS as an effective water treatment method and today it is used by more than one million users in at least 20 developing countries [1],[2].

How it works

SODIS works by two mechanisms: radiation and pasteurization. Ultraviolet (UV) rays from the sun are classified into three categories based on their wavelength: A, B, and C. UV-A radiation (320-400 nm), the UV light closest to the visible light spectrum, is largely the solar radiation that reaches the surface of the earth. Fortunately, UV-A light also has a lethal effect on human pathogens in water. These pathogens are adapted for life inside the human gastrointestinal system and are more vulnerable to the harsh conditions in the environment. Solar radiation damages the nucleic acids and enzymes in pathogens which interrupts normal cell function and leads to cell death. UV radiation also reacts with oxygen dissolved in the water, producing highly reactive forms of oxygen (oxygen free radicals and hydrogen peroxides) which also interfere with pathogen cells and leads to their death.

Let's Get Technical: UV-A Radiation

UV-A radiation (320-400 nm) is primarily responsible for the inactivation of microorganisms. Visible violet light (400-450 nm) alone has very little bactericidal effect. However, when the two are combined the inactivation rate of E. coli is increased by a factor of three[3]. Viruses are more resistant but are also killed within 6 hours. Parasites are the least resistant. Cryptosporidium require at least 10 hours of solar radiation. Amoebas do not die until the water temperature exceeds 50°C for one hour [4].

At temperatures of 20-40°C (which do not affect bacterial inactivation) a fluence, or solar intensity, of at least 500 W/m^2 (all spectral light) is required to reach an energy dose of 555 $W{\bullet}h/m^2$ in the range 350-450 nm in order to achieve a 3-log reduction in fecal coliform. This is approximately equivalent to 6 hours of mid-latitude midday summer sunshine [3],[1].

The second mechanism, pasteurization, uses the sun's thermal energy to heat the water. Water does not have to be boiled to kill many pathogens. Heating the water to above

Let's Get Technical: Effects on Pathogens

Table 1 Reduction of Microorganisms with SODIS [4]

		Disease	Reduction with SODIS (6h, 40°C)
Bacteria	Escherichia coli	Indicator for water quality and enteritis	99.999%
	Vibrio cholera	Cholera	99.999%
	Salmonella species	Typhus	99.999%
	Shigella flexneri	Dysentery	99.999%
	Campylobacter jejuni	Dysentery	99.999%
	Yersinia enterocolitica	Diarrhea	99.999%
Virus	Rotavirus	Diarrhea, dysentery	99.9 - 99.99%
	Polio virus	Polio	99.9 - 99.99%
	Hepatitis virus	Hepatitis	Reports from users
Parasites	Giardia species	Giardiasis	Cysts rendered inactive
	Cryptosporidium species	Cryptosporidiasis	Cysts render inactive after >10h exposure
	Amoeba species	Amibiasis	Not rendered inactive. Water temperature must be >50°C for at least 1h.

Figure 1 Temperature Dependence of E. coli Inactivation [3], [2]

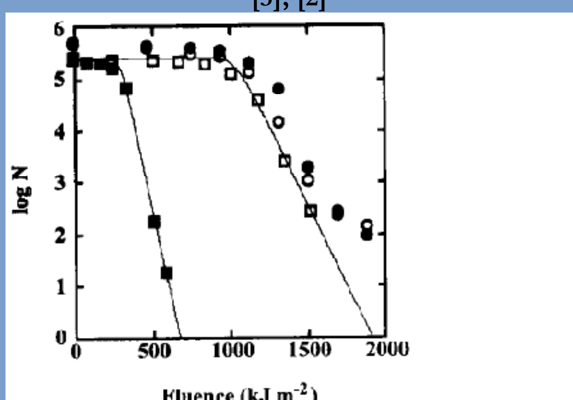


Fig. 10 Temperature dependence of the inactivation curves of *E. coli* using the undoped lamp with the 320 nm cut-off filter: (○) 20 °C, (●) 30 °C, (□) 40 °C, (■) 50 °C.

50°C (90°F) for an hour or more can have the same effect. This can be achieved by painting the bottom half of the water container black or by placing in on a reflective surface. If a high enough water temperature is maintained, the exposure time of the containers may be reduced to one hour [1].

The combination of the radiation and pasteurization mechanisms has a synergistic effect, achieving better results than the sum of the two processes individually. At 50°C, only one fourth of the amount of UV light is required to inactivate the same number of fecal coliforms as would be required at 30°C. When two stress factors, UV-A radiation and increased water temperature are combined, only 140 W•h/m^2 are required to achieve a 3-log reduction of fecal coliforms [1].

Furthermore, studies have shown that E. coli exposed to UV-C radiation are inactivated in only a few seconds but exhibit regrowth after one week. However when exposed to sunlight over several hours no regrowth was observed after two weeks time [5]. When used effectively, the SODIS method has shown to prove effective when coliform levels exceed 100,000/100mL [6].

Let's Get Technical: Effects on Pathogens cont'd

Table 2 Destruction Temperature for Microorganisms [7]

Microorganisms	Time and Temperature for 100% Destruction		
	1 min	6 min	60 min
Enterovirus			62°C
Rotavirus	63°C for 30 min		
Fecal Coliforms	80°C		
Salmonellae		62°C	58°C
Shigella		61°C	54°C
Vibrio Cholerae			45°C
Entamoeba Hystolitica cysts	57°C	54°C	50°C
Giardia cysts	57°C	54°C	50°C
Hookworm eggs and larvae		62°C	51°C
Ascaris eggs	68°C	62°C	57°C
Schistosomiasis eggs	60°C	55°C	50°C
Taenia eggs	65°C	57°C	51°C

When to use it

- Between latitudes 15-35° North or South (0-15° N or S are also possible but less favorable)
- In remote areas where electricity and materials are limited
- When financing is limited
- When the microbial quality is the only major concern

User Acceptability

Pros

-No chemicals required
- No taste effects
-Low cost
- Ease of use

Cons

-Low volume yield
- Time requirement
-Little perceived effect
-Water is initially hot

When not to use it

- When water is not clear (> 30 NTU)
- When PET bottles are not vailable
- When large volumes of water need to be treated
- When there is not at least 6 hours of bright, sunny weather daily and year round
- When chemical quality of water is a concern (i.e. water polluted with fertilizer, pesticide, or arsenic)
- For children or people with a compromised immune system

Let's Get Technical: Turbidity

Turbidity is a measure of optical scattering caused by suspended particles in water which reduce the ability of solar radiation to penetrate the water. The figure at right demonstrates the reduction of solar radiation penetration with depth for waters of differing turbidities. In water with 26 NTU, radiation is decreased by 50% at a depth of 10cm. Suspended particles may also harbor microorganisms and prevent them from being irradiated. If the water to be treated has greater than 30 NTU it must be pretreated by settling, filtering, or some other method. If the turbidity cannot be reduced, the water must be disinfected by heating rather than UV radiation (by boiling or solar pasteurization) [1].

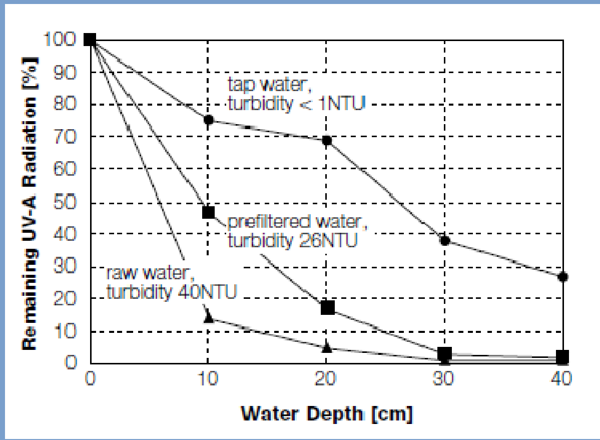


Figure 2 Effects of Turbidity on UV Penetration [8]

Let's Get Technical: Weather and Climate

The efficiency of SODIS is dependent on the amount of available solar radiation. This, however, varies across regions, latitudes, seasons, and time of day. Therefore it is important to be sure that the location consistently has sufficient sunlight across these variations.

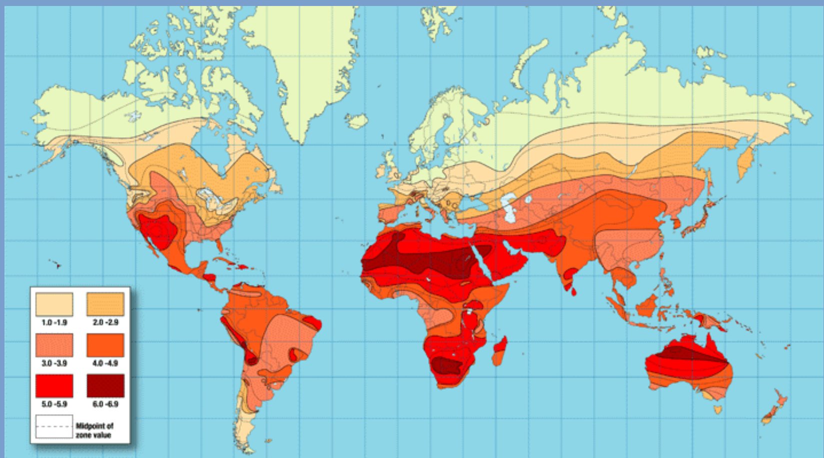


Figure 3 Global Solar Radiation Intensity (kWh/m²)

The most favorable locations for SODIS tend to be between 15 and 35° of latitude (N or S). These tend to be semi-arid regions with high levels of solar radiation, low cloud cover and limited rainfall. Latitudes 0°-15° N or S are also favorable but due to high humidity, cloud cover tends to be greater in this region and thus the amount of solar radiation annually is lower. However, the majority of the world's developing countries are between 35°N and 35°S and can therefore utilize solar energy as a means of disinfecting drinking water [1].

Use this test!

Place a bottle filled with water upright on top of the SODIS logo. If you can read the letters of the logo through the water, the turbidity is less than 30 NTU. If you can see the sunrays of the logo, the turbidity is less than 20 NTU.

Materials and Installation

Clear plastic or glass bottles, and plastic bags are good transmitters of UV-A light and are acceptable containers for the SODIS method. Plastic bags designed especially for SODIS are available and have high treatment efficiencies. Bottles are generally better for the SODIS method because they are much more user friendly. They seal completely, are less likely to leak or break, and the water can be easily used from them directly after it is disinfected. However, the material and shape of the container affect the efficiency of the process. Bottles should be less than 3L in volume and the water depth should not exceed 10cm when the bottles are laid on their side.

Glass and plastic bottles both have their advantages and disadvantages. Some types of glass, such as ordinary window glass, transmit very little UV-A light. Others, such as Corex, Vycor, Pyrex, and Quartz, transmit significantly more. However, these types of glass may be too expensive or difficult to attain to be an appropriate material for SODIS. Plastics also contain UV stabilizer additives to protect their contents from oxidation and UV radiation.

	Plastic Bags	Plastic Bottles	Glass Bottles
Advantages	✓Faster heating and higher temperatures ✓More efficient inactivation of bacteria and viruses	✓Low weight ✓Robust ✓Low cost	✓No scratches (longer lasting) ✓No photoproducts ✓Heat resistant
Disadvantages	▪ Water smells plastic ▪ Difficult to handle ▪ 3-6 month lifespan ▪ Requires another container ▪ SODIS bags aren't readily available	▪ Easily scratched ▪ Limited heat resistance ▪ May produce photoproducts (if not PET)	▪ Easily broken ▪ Higher weight ▪ Higher cost

Plastic bottles are made of either PET (PolyEthylene Terephtalate) or PVC (PolyVinyl Chloride). However, it is recommended that PET bottles rather than PVC are used because they contain fewer additives (less than 1%). Under UV radiation, photochemical reactions in the plastic occur, producing optical and property changes in the material. Over time, the UV-stabilizer additives in the plastic are depleted reducing the UV-A transmittance of the material. These photoproducts are also a potential health risk. However, studies have shown that they are generated on the outer surface of the bottles and no leaching of the products into the water was observed.[9]

How to Distinguish PET from PVC:

- The recycling mark for PET is 1, the mark for PVC is 3
- PET bottles often have a bluish tint which is especially noticeable at the edges of a piece of bottle material that has been cut out
- If PVC is burnt, the smoke is pungent and acrid, where the smoke of PET is sweet
- PET burns more easily than PVC

No installation is required to use the SODIS method as long as users have a roof or other location which receives direct sunlight for at least 6 hours a day. However, a stand made of a small corrugated iron platform on top of a wooden post may be constructed near the home if more direct sunlight or a more reflective surface are needed.

Let's Get Technical: PET and Health

In the presence of UV-A and UV-B light, PET undergoes photochemical reactions causing optical and mechanical property changes. The mass spectroscopy figures below indicate the chemical analysis the inner and outer surfaces for new bottles and those exposed to the sun for 6 months. The outer surface shows a clear change from the new to old bottle but relatively little change is exhibited on the inner surface. Therefore, the photochemical ageing of PET has little affect the quality of water contained in the bottle with respect to antimony, aldehydes, adipates and phthalates, or organic photoproduct. In fact, a study by the Swiss Federal Institute for Materials Testing and Research concluded that after 17 hours of testing in 60°C water, levels of adipates and phthalates were on the average level found in high quality tap water and well below the WHO guidelines for drinking water. Thus it is unlikely that the use of PET bottles for SODIS will lead to health concerns.[9], [10], [11], [12]

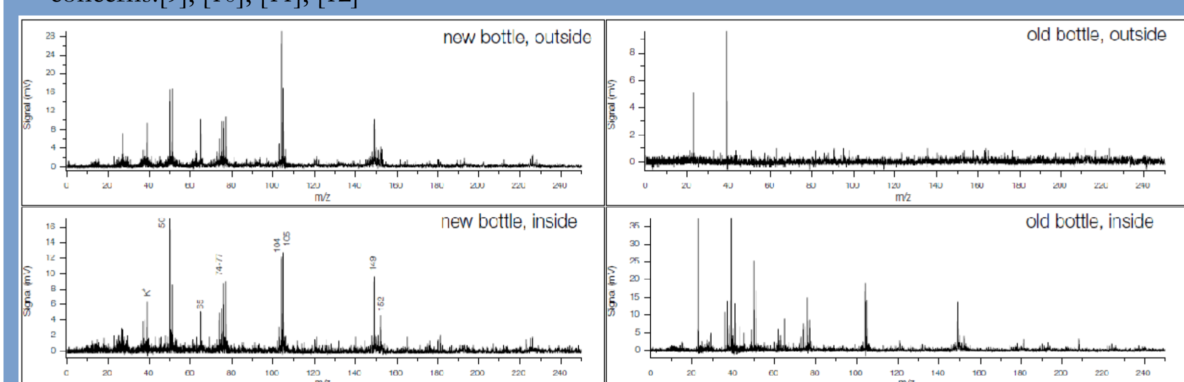


Figure 4 Mass Spectrograph of Inside and Outside of New and Old PET Bottles

Cost: $

SODIS is extremely inexpensive to initiate and use. The only major costs for the method are the initial and replacement PET bottles. These may also be attained by recycling the bottles from other uses at no cost as long as the bottles are in good condition. If a platform must be constructed as a treatment location, materials and local labor will be needed at a small cost dependent on the location.

Training

Actors	Roles	Skills Required
Family member	Clean containers, fill containers daily, place containers in the sun, use the water	☺
Local craftsman	Build a platform to hold containers in the sun	
External support	Train family members, check water quality	

☺ Simple, often requires awareness raising or training
Level of technical skill required

Source: [13]

Use

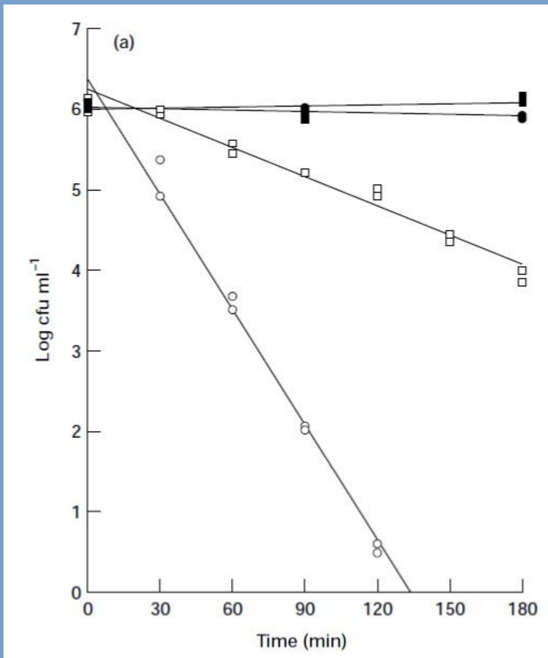
The SODIS method is simple to use:

1. Collect containers and thoroughly wash them. PET bottles are recommended. Bottles should be clear (not colored), no larger than 3L, and have all labels removed.
2. Check that the water is clear enough (> 30 NTU). If not, it must be pretreated
3. Fill the containers three-quarters full with water, tighten the cap, and shake for 20 seconds.
4. Fill the remainder of the container and tightly secure the cap.
5. Lay the container flat on a roof or reflective surface for at least 6 hours from morning to evening in bright sunny weather where no shadows will cross them, or for 2 consecutive days if the sky is more than 50% cloudy.
6. The water is ready for consumption! Bottles can be stored as long as the bottle is kept unopened in a cool, dark place. The water should only be transferred to another clean container to prevent recontamination.

Use this Test!

Create and internal temperature gauge by pressing the threaded end of a screw weight into a ball of paraffin wax so that it floats. When the wax melts, the weight drops to indicate the water is approximately 50°C. After one hour at this temperature most microorganisms will be killed.

Let's Get Technical: Oxygenation



SODIS is more efficient in water that contains high levels of oxygen. The free radicals and hydrogen peroxides produced from oxygen in the presence of sunlight react with cell structures and kill pathogens. Aerobic conditions can be achieved in SODIS bottles by shaking a three-quarters filled bottle for about 20 seconds and then filling the remainder of the bottle. Further studies have shown, however, that the bottles should not be shaken again once they are placed in the sun. Moving the bottles once the disinfection process has begun will reduce the efficiency of the process because dissolved oxygen in the water is released with agitation [14].

Figure 5 Inactivation of Exponential Phase E. coli in Full Sunlight Aerobic (O) or Anaerobic (□) Conditions, and in Dark Aerobic (●) or Anaerobic (■) Conditions[15]

Removal

	Bacteria	Virus	Protozoa	Helminth	Algae	Fe/Mn
Lab	**Med/High** (McGuigan 1998, Berney 2006, Reed 1997, Wegelin 1994)	**High** (Fujioka 2002)	**High** (Gaafar 2007, Lonnen 2005) Including C. parvum (Mendez-Hermida et al 2005, King 2008)	**Med/High*** (Skinner & Shaw 1998, CAWST)	**None** (National Academy of Sciences, 2008)	**None** (National Academy of Sciences, 2008)
Field	**High** (Sobsey 2008, Conroy 1999)	**High** (Sobsey 2008)	-	-	-	**-**

	Fl	As	Salt	Odor & Taste	NOM	Turbidity
Lab	**None** (National Academy of Sciences, 2008)	**None** (National Academy of Sciences, 2008)	**None** (Skinner & Shaw 1998)	**None** (Skinner & Shaw 1998)	**None**	**None**
Field	-	-	-	-	**None**	**None**

Sources: [16], [17], [15], [3], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27]

Operations and Maintenance

Activity and Frequency	Materials and Spare Parts	Tools and Equipment
Daily		
- Fill bottles and place in the sun - Remove bottles after sun exposure	Raw water	
Occasionally		
- Wash bottles	Soap, clean water	Bottle brush
Every 6-12 months		
- Replace PET bottles	New PET bottles	

Source: [13]

Let's Get Technical: PET Maintenance

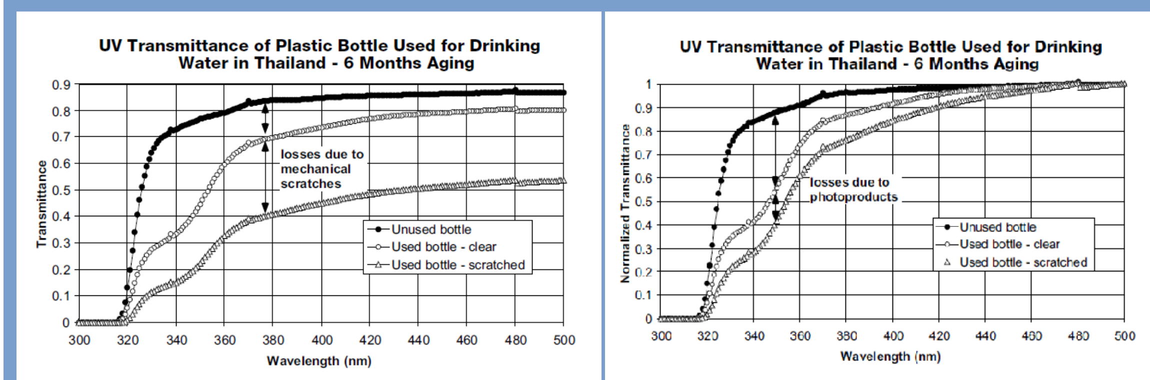


Figure 6 Transmittance Loss in Scratched PET Bottles [10]

The figures above show transmittance losses of plastic bottles due to physical and chemical property changes. The figure of the left shows transmittance losses due to mechanical scratches while the figure on the right shows losses due to photoproducts. The loss of UV transmittance degrades the effectiveness of the SODIS method because threshold requirements of UV and thermal radiation cannot be met. Therefore it is imperative that bottles be replaced every 6-12 months, or sooner if they become significantly scratched [10].

Limitations and Potential Problems

- If turbidity varies, especially from below 30 NTU to above 30 NTU, and users have not been trained to check turbidity or check it daily.
- A continuous supply of new PET bottles is not available.
- Large seasonal or daily variation in solar radiation
- Inadequate sanitation and hygiene habits which may lead to recontamination

Longevity and Scalability

Very few studies have been conducted on the prolonged use of the SODIS method and consumers' willingness to continue to use the method. One of the longest studies to date lasted 12 months and found that even during the study period 85% of children consumed non-SODIS treated water.[28] Another study found that community use varies from 20-80%.[26] Therefore, the longevity of the SODIS method is limited without continual and persistent follow-up.

The easiest way to scale up SODIS is simply to treat more containers daily for which the greatest requirement would be the containers themselves. Scientific studies have been conducted on the possibility of using the radiation and pasteurization processes of SODIS on a larger scale in a system known as a batch reactor. However, initial studies showed that the success of this process was limited on very cloudy days. [7]

For Training Material and More Information:

http://www.sodis.ch/index_EN

References:

1. EAWAG, *Solar Water Disinfection: A Guide for the Application of SODIS*. 2002, EAWAG: Dubendorf.
2. Lantagne, D.S., R. Quick, and E.D. Mintz, *Household Water Treatment and Safe Storage Options in Developing Countries: A Review of Current Implementation Practices*, in *Water Stories: Expanding Opportunities in Small-Scale Water and Sanitation Projects*, M. Parker, A. Williams, and C. Youngblood, Editors. 2007, Woodrow Wilson International Center for Scholars: Washington DC. p. 17-38.
3. Wegelin, M., et al., *Solar Water Disinfection: Scope of the Process and Analysis of Radiation Experiments*. Journal of Water Supply Research and Technology-Aqua, 1994. **43**(3): p. 154-169.
4. EAWAG. *Microbiology*. 2009 [cited 2011 February 21]; Available from: http://www.sodis.ch/methode/forschung/mikrobio/index_EN.
5. EAWAG. *Technical Note #11: SODIS Efficiency: Covered Sky Conditions*. 2009 [cited 2011 February 21]; Available from: http://www.sodis.ch/methode/anwendung/factsheets/covered_sky_e.pdf.
6. EAWAG. *FAQs*. 2009 [cited 2011 February 21]; Available from: http://www.sodis.ch/methode/faqs/index_EN.
7. Sommer, B., et al., *SODIS-An emerging water treatment process*. Journal of Water Supply Research and Technology-Aqua, 1997. **46**(3): p. 127-137.
8. EAWAG. *Technical Note #7: Turbidity and Water Depth*. 1998 [cited 2011 February 21]; Available from: http://www.sodis.ch/methode/anwendung/factsheets/turbidity_waterdepth_e.pdf.
9. Wegelin, M., et al., *Does sunlight change the material and content of polyethylene terephthalate (PET) bottles?* Journal of Water Supply Research and Technology-Aqua, 2001. **50**(3): p. 125-133.
10. EAWAG. *Technical Note #3: Ageing Effects on PET Bottles*. 1998 [cited 2011 February 23]; Available from: http://www.sodis.ch/methode/anwendung/factsheets/ageing_e.pdf.

11. EAWAG. *PET-bottles*. 2009 [cited 2011 February 21]; Available from: http://www.sodis.ch/methode/forschung/pet/index_EN.
12. Kohler, M. and M. Wolfensberger, *Migration of organic components from polyethylene terephthalate (PET) bottles to water*. 2003, Swiss Federal Laboratories for Materials Testing and Research: Dubendorf.
13. Brikké, F. and M. Bredero, *Linking Technology Choice with Operations and Maintenance in the Context of Community Water Supply and Sanitation*. 2003, World Health Organization and IRC Water and Sanitation Centre: Geneva.
14. Kehoe, S.C., et al., *Effect of agitation, turbidity, aluminium foil reflectors and container volume on the inactivation efficiency of batch-process solar disinfectors.* Water Research, 2001. **35**(4): p. 1061-1065.
15. Reed, R.H., *Solar inactivation of fecal bacteria in water: the critical role of oxygen.* Letters in Applied Microbiology, 1997. **24**: p. 276-280.
16. McGuigan, K.G., et al., *Solar disinfection of drinking water contained in transparent plastic bottles: characterizing the bacterial inactivation process.* Journal of Applied Microbiology, 1998. **84**(6): p. 1138-1148.
17. Berney, M., et al., *Efficacy of solar disinfection of Escherichia coli, Shigella flexneri, Salmonella Typhimurium and Vibrio cholerae.* Journal of Applied Microbiology, 2006. **101**(4): p. 828-836.
18. Fujioka, R.S. and B.S. Yoneyama, *Sunlight inactivation of human enteric viruses and fecal bacteria.* Water Science and Technology, 2002. **46**(11-12): p. 291-295.
19. Gaafar, M.R., *Effect of solar disinfection on viability of intestinal protozoa in drinking water.* Journal of the Egyptian Society of Parasitology, 2007. **37**(1): p. 65-86.
20. Lonnen, J., et al., *Solar and photocatalytic disinfection of protozoan, fungal and bacterial microbes in drinking water.* Water Research, 2005. **39**(5): p. 877-883.
21. Méndez-Hermida, F., et al., *Disinfection of drinking water contaminated with Cryptosporidium parvum oocysts under natural sunlight and using the photocatalyst TiO2.* Journal of Photochemistry and Photobiology B: Biology, 2007. **88**(2-3): p. 105-111.
22. King, B.J., et al., *Solar UV reduces Cryptosporidium parvum oocyst infectivity in environmental waters.* Journal of Applied Microbiology, 2008. **104**(5): p. 1311-1323.
23. Skinner, B. and R. Shaw, *Household Water Treatment: 1*. Waterlines, 1998. **17**(2): p. 15-18.
24. CAWST. *Household Water Treatment and Safe Storage Fact Sheet: Solar Disinfection*. 2009; Available from: http://www.cawst.org/en/resources/pubs/category/25-fact-sheets-academic.
25. National Academy of Sciences. *Safe Drinking Water is Essential: Technologies*. 2008 [cited 2011 May 9]; Available from: http://drinking-water.org/flash/en/water.html?_3_00_00.
26. Sobsey, M.D., et al., *Point of Use Household Drinking Water Filtration: A Practical, Effective Solution for Providing Sustained Access to Safe Drinking Water in the Developing World.* Environmental Science & Technology, 2008. **42**: p. 4261-4267.
27. Conroy, R.M., et al., *Solar disinfection of water reduces diarrhoeal disease: An update.* Archives of Disease in Childhood, 1999. **81**(4): p. 337-338.
28. Rose, A., et al., *Solar disinfection of water for diarrhoeal prevention in southern India.* Archives of Disease in Childhood, 2006. **91**(2): p. 139-141.

Filtration

Filtration is a physical removal mechanism whereby water passes through a porous material removing and retaining contaminants. There is a wide variety of filtration methods used for drinking water treatment in the developing world whose removal capabilities are as varied as the materials they use.

Traditional filters are attractive for their affordability, availability, and ease of use. They use size exclusion and adsorption, or the process of particles becoming attached to the filtration material, to remove particles. The removal capabilities of traditional filters vary by filtration material but generally have high particulate removal and low to moderate pathogen removal. Filter materials may include granular media such as sand or gravel, or other natural material such as cotton fiber, sponges, charcoal, fabric, and diatomaceous earth. Rapid filters often use sand and are combined with coagulants and remove contaminants through adsorption and size exclusion across a deep filter bed. Roughing filters use a layered combination of two or more filtration materials, often sand and different sizes of gravel.

Slow sand and BioSand filters expand upon traditional filtration by adding a biological component to the treatment. Both of these filtration methods use a tall thin container packed with a sand bed through which water passes and which, over time, ripens to become host to a multitude of bacteria, algae, protozoa, rotifers, copepods and aquatic worms. These microorganisms assist in the removal of harmful pathogens. BioSand filters are generally smaller than traditional slow sand filters and use a modified container so that standing water remains in the filter at all times in order to maintain the biological layer.

Ceramic filters utilize a natural fired clay container that is usually either bowl or flower pot shaped, or candle shaped. Water passes through the small pores in the ceramic, removing bacteria and protozoa, and empties into a larger bucket below with a spigot.

Often the ceramic is impregnated with colloidal silver which aids in disinfection. These filters are generally low cost, long lasting and can be manufactured in country. However, their flow rate is low at only 1-2 liters per hour.

Bag or cartridge filters are simple filters that use a woven cloth bag or cartridge wound with a filament filter to remove contaminants. Depending on the material, bag filters are capable of removing contaminants as small as one micron in diameter meaning they are highly effective for removing turbidity but not for bacteria or viruses. Furthermore, they must be discarded and replaced when they become clogged or the flow rate drops too low. Like bag filters, cartridge filters are designed for lighter contaminant loads. They are often cylindrical with a hollow center core surrounded by fiber or pleated material. Their capabilities are dependent upon the type and thickness of the material but must be replaced when clogged. Both bag and cartridge filters are designed for small scale applications.

Waves for Water provides a more advanced application of filtration technology. This product combines bag and ceramic filters to remove particles larger than 0.5µm, which includes most bacteria, viruses, chemicals and heavy metals. The product will produce 1 gallon per hour, last 6-8 months, and costs US$25.

BioSand Filter

The BioSand Filter (BSF) was developed in the 1990s by Dr. David Manz in Calgary, Canada. It is an adaptation of another sand filtration method, slow sand filtration, to be used for intermittent operation and therefore perfect for household use. Unlike rapid sand filtration which is usually used for removal of particulate matter within a larger treatment system, BioSand filtration combines biological and filtration processes to remove pathogens, suspended particles, and some minerals. It is estimated that as of 2009, more than 200,000 BioSand Filters have been constructed in over 70 countries.

How it works

Contaminated water poured into the filter passes through the layers of the filter and is cleaned by four mechanisms: mechanical trapping, predation, adsorption, and natural death.
Water entering the filter contains nutrients and oxygen, as well as dirt and pathogens. In the first 1 cm of the sand is an active biolayer. Microorganisms living in the biolayer eat pathogens in the water as it passes through the sand layer. Also, particles larger than the gaps between the sand particles are trapped and removed from the water. As the water continues to pass through the filter, pathogens attach to one another, to other materials suspended in the water, and to the sand particles as they collide with them. When pathogens reach the bottom of the filter, there are no longer enough nutrients or oxygen to sustain them and they die off naturally. Water then passes through the gravel layers, which hold the sand inside the filter, and into the outlet tube from which it is collected.

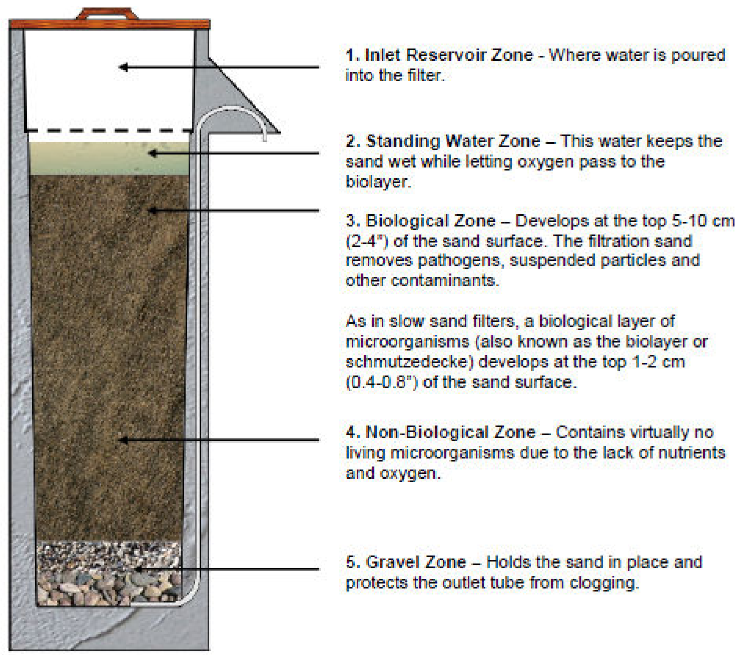


Figure 1 BioSand Filter Components [1]

The period when the filter is not in use is called the "pause period". This is also a very important process in the filters function. During this time the filter is still full of water, however water is no longer flowing from the outlet tube. Bacteria in the biolayer consume the nutrients and pathogens in the water and the flow rate through the filter is restored. The pause period should last between 1 and 48 hours. If the interval between uses of the filter is too long, the beneficial bacteria in the biolayer will die due to lack of oxygen and nutrients, and the filter will be less effective for future uses.

Let's Get Technical: The Biolayer

The biolayer is the component of the filter responsible for removing pathogens from the source water. Without it, the filter can only remove 30-70% of pathogens through adsorption and mechanical trapping. The addition of the biolayer increases this to as much as 99% [1].

Because of the low hydraulic loading and the small pore size between sand particles, the majority of the suspended particles in the water are removed in the first 2cm of the sand layer. Over time these removed solids form a film on top of the sand, known as the schmutzdecke, as well as a biologically active layer within the first 1cm of the sand (sometimes referred to collectively with the schmutzdecke under the same term). The schmutzdecke is usually comprised of organic matter, silica, and iron, and can itself contribute to filtration of colloidal particles from the source water as well as biological activity. For this reason, it is important that a diffuser plate or other device be used to protect the schmutzdecke from disturbance when new raw water is added to the filter [2].

The biolayer is established in the first few weeks of the filter's life. During this time bacteria, algae, protozoa, and small invertebrates grow in the top few centimeters of the sand where oxygen is still able to diffuse into the system. As the biolayer grows, the removal rate of the system increases, and thus it is important that the biolayer be fully developed. This may take 30 days or more. Furthermore, the biolayer is not visible nor distinguishable from the remaining sand - it should not form a green slimy film on the sand - and therefore a visible check of the system cannot indicate when the biolayer is developed [1],[2].

Once the biolayer is established, it purifies the raw water by at least four theorized processes. These include hostile environmental conditions not suited for many enteric bacteria, competition for food and predation, the oxidation of natural organic matter during metabolism, and excretion of poisons [1],[2].

Let's Get Technical: Fluid Pressure and Intermittent Operation

The elevated level of the water outlet tube is the element of the filter which allows it to be operated intermittently. It works by of the principles of fluid pressure. In the figure at right, fluid in a system open to atmospheric pressure tends toward equilibrium. However, when additional pressure is added to one side, the fluid level lowers on that side and rises towards the other to balance the system.

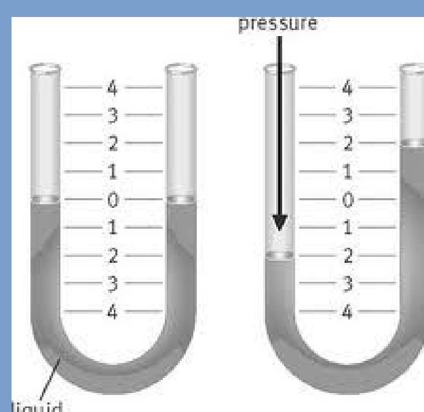


Figure 2 Fluid Pressure Diagram

Let's Get Technical: Fluid Pressure and Intermittent Operation cont'd

By raising the outlet tube above the height of the sand, a system such as this is created in the filter. When water is added to the filter, the additional pressure forces water through the system and out of the outlet tube in order to balance the system. When the level of standing water lowers to the height of the outlet tube, the system is balanced. More importantly, there is still water in the filter at this point which allows the biolayer to thrive even when water is not continuously flowing through the filter. For this reason, it is important that nothing is added to the outlet which would alter the water level or force air through the filter.

When to use it

- When access to electricity or supplies is limited

When not to use it

- When turbidity is >50 NTU
- When a consistent water source is not available
- When chemical or viral contamination are a large concern
- In transient communities
- When external support is not regularly available.

User Acceptability

Pros
-Ease of use
-Produces large volumes
-Produces clear, better tasting water

Cons
-Should be used with other treatment including chlorination
-Completed filter cannot be moved

Materials and Installation

The installation process for the BSF has many stages. The first step is to gather the tools and materials. A complete list can be found at the end of this section. Selecting the sand and gravel that will be used for the filter is an important part of the filter's construction. This step will highly affect the performance of the filter. The table below describes the characteristics for a good sand selection:

Should	Should NOT
• Use sand with a lot of gravel that is up to ½" in diameter • When you pick up a handful of the sand, you should be able to clearly see the individual grains and they should be of different sizes and shapes • You should be able to feel the coarseness of the grains	• Contain organic material such as leaves, sticks, loam, or grass • Contain possible contamination from microorganisms. Avoid areas that are frequently used by humans or animals • It should not be very fine or contain a lot of silt or clay

Let's Get Technical: Sand and Gravel Selection

Crushed rock is the best type of filtration sand because it is less likely to contain pathogens, and has a mixture of grain sizes which more effectively filters a variety of materials from the raw source water. However, it may be more expensive and more difficult to obtain. The next choices are sand from high on the banks of a river, followed by riverbed sand. These usually have fine grains and contain pathogens, chemical contamination, salt, and natural organic material from human or animal use of the river and runoff into the river. Using these types of sand may actually increase the contamination in the filter, and should therefore be treated before they are used in a filter. Disinfection can be achieved with a chlorine bath and drying in the sun, but organic material removal (elimination of the source of nutrients) can only be achieved through incineration which is usually prohibitively expensive and time consuming [1],[3].

Once the sand and gravel are selected, they must be sieved. The sand should be passed through four different sieves to separate the sand and gravel grains by size. These will be used in different layers in the filter. Material retained in the ½" sieve is too large to use and should be thrown out as waste. Gravel retained in the ¼" sieve should be used for the drainage layer and gravel retained in the 0.03" sieve should be used for the separation layer. The sand that passes through this sieve should be washed and used for the sand filtration material but should not be used for concrete because it is too fine.

Use this Test!

Squeeze a handful of dry sand. When you open your hand, what does the sand do? If the sand balls up or sticks together, it contains too much clay or dirt. The sand should pour smoothly back out of your hand.

Tips:

- Make sure the sand is completely dry before sieving. Wet sand will plug the screen making it difficult to sieve
- If the sand absolutely cannot be dried, pouring clean, clear water over the sand may help carry it through the sieve
- Have containers ready to catch each batch of material as it passes through the sieve so that they stay separated and can be easily moved

After the sand and gravel are separated, they must be washed. Washing the sand controls the flow rate through the filter as well as prevents contamination from being introduced. Sand that is not washed enough will slow the flow rate to the point where it is impractically slow, or will clog too frequently. This sand may also still harbor some contaminants. The suggested flow rate for a filter depends on the container, but usually varies from 0.4-0.8L/minute. If the flow rate is too slow, the sand should be washed again. However, if the flow rate is too fast the filter will not work properly. Most of the mechanisms by which the filter works will not have sufficient time to remove pathogens and particles if the flow rate is too fast.

Use this Test!

Put some sand into a clear container with an equal amount of clear water, put the lid on and swirl it. Looking from the side of the container, 3-4 seconds after you stop swirling, you should be able to see the surface of the sand. Use this same number of washes each time the filter is re-sanded with sand from the same source [1].

Not washed enough

About right

Washed too much

Let's Get Technical: Flow Rate

Flow rate is an important parameter of a BSF. A lower flow rate produces greater microbial removal for a number of reasons. First, a longer contact time (time that the water takes to pass through the filter layers) gives the biolayer more time to consume the pathogens in the raw water. This is especially important in cooler climates where biological activity is decreased. Second, a high flow rate forces pathogens and nutrients farther down into the sand layer where the biolayer does not have enough oxygen to survive. This would also require an increased sand layer depth which could make the filter impractically tall. Finally, a slower flow rate causes less physical disturbance to the biolayer, allowing it to become more developed [4].

The flow rate through the filter is a function of many properties of both the sand and the raw water. Flow rate is described by the following equation under Darcy's Law:

$$Q = K(A \cdot h/L)$$

where Q is the flow rate in m^3/hr, K is the hydraulic conductivity in m/hr (itself a property of the fluid's viscosity and density and the sand), A is the cross sectional area of the filter layer in m^2, h is the head loss in m, and L is the length of the filter bed [4].

Therefore, changing the temperature of the water, type of sand, or length of the filter will affect the flow rate of the filter. These are important considerations, especially if the filter construction and operation are varied from the standard procedure summarized in this manual in order to accommodate the implementation conditions. A study by Jenkins et al (2009) showed that the grain size of the sand, the residence (or holding) time of the water, and the hydraulic loading rate (i.e. how much water is added to the filter at once) greatly affect the microbial removal rate of the filter. Knowing the priority of these factors may allow certain properties of the filter to be altered to better meet local conditions and improve performance while still meeting technical requirements, such as optimal flow rate [5].

Once the sand and gravel are washed, the filter can be assembled. There are different options for filter containers which may be selected based upon what is most appropriate for the region. However the shape and size of container will affect the depth of each filtration layer which must be adjusted to control the flow rate through the filter.

Do not use plastic tubing with an inner diameter less than 1/4" or greater than 3/8". These sizes will produce poor flow rates in the filter and the tubing may become blocked or protrude from the filter walls.

Plastic containers offer greater mobility because they are much lighter. A completed cement filter box usually weighs around 210 lbs and the sand may add another 100 lbs making it difficult to move.

Figure 3 PVC container with a local ceramic storage vessel

Figure 4 Hydraid plastic container

Figure 5 Locally constructed concrete box

Plastic containers weigh 140 lbs when filled with sand and their installation is much shorter at only about 30 minutes. However, plastic containers may have to be brought in-country making them more expensive to install. Once the container is selected and installed, the sand and gravel media can be added. The filter should be flushed and the correct flow rate established. Then the outlet tube should be disinfected. Finally, after the biolayer has ripened, the filter is ready to use.

Tip:

- The filter container should be filled with water before the sand and gravel media are added. The sand and gravel should be poured into the water to prevent air pockets from forming within the layers.

Cost: $$

The cost of the filter depends on the container used and the availability of the sand and gravel media. Concrete containers cost US$ 12-30, not including the cost of the mold or sand and gravel. The molds can cost between US$ 250 and $900 [6]. Plastic containers, like the Hydraid filter, cost around $75 a piece and often have to be bought in bulk but the sand and gravel materials may also be included [7],[8]. There is no operation cost.

Training

Actors	Roles	Skills Required
Water user	Collect water, assist in cleaning the filter	☺
Local caretaker	Regulate flow, keep site clean, clean the filter	
Local craftsman **Or** **External support**	Fabricate metal filter molds, cast cement filter containers or Install prefabricated filter container	 
External support	Train the care taker, monitor water quality	
☺ 	Simple, often requires awareness raising or training Level of technical skill required	Adapted from:[9]

Use

The BSF is designed to be operated intermittently. Ideally the filter should be used a few times a day, but no less than once every two days. The best results are achieved when the same source water is used every time. This is especially important if more than one family shares a filter. See below for more discussion about the source water. It is also important that the source water not have more than 50 NTU of turbidity. Excess suspended material in the water which causes turbidity will clog the filter too quickly.

1. Collect source water. Pre-treat the water if it has more than 50 NTU of turbidity. This can be done with a strainer or another filter.
2. Make sure the diffuser is in place
3. Place a CLEAN storage container under the filter outlet. Raise it with a box or stool as close as possible to the outlet tube. The best storage containers should be strong, have a small opening with a tight fitting cap or lid, and be easy to clean.
4. Pour the source water into the filter and place the lid on the filter.
5. The filtered water should be left in a cool shady place and used as soon as possible.
6. To insure the filtered water is of the highest quality, a disinfectant such as chlorine should be used.

7. Clean the filter as needed by adding water to the filter and agitating the top ½ centimeter of filter material. The resulting dirty water at the top of the filter should then be decanted to remove the suspended particles.

One of the advantages of the simplicity of the BioSand Filter is that it can be used by children. This makes it possible for filters to be placed in schools so that clean water for drinking and proper hygiene is available beyond the home.

Let's Get Technical: Source Water

It is important that the best available water is used in the filter. The better the input water, the better the output water will be. Natural ground water or surface water may be used, as well as water from a municipal distribution center if parasitic contamination is the main concern and the water does not have a high chlorine residual. Remember, chlorine will kill the beneficial bacteria in the filter and decrease its effectiveness. However, water from distribution systems in developing countries, especially in rural areas, does not often have a high chlorine residual.

Over time, the biolayer becomes accustomed to the level of contaminants and nutrients in the source water. It may take several days for it to adjust if these are altered, reducing the removal efficiency of pathogens during this time. Therefore, it is ideal to use water from the same source each time to ensure the quality of the output water [2],[10].

Operations and Maintenance

Activity and Frequency	Materials and Spare Parts	Tools and Equipment
Daily (or every other day)		
- Fill the filter with raw water - Check the flow rate	Raw water Watch	Bucket
Every 6 weeks or as needed		
- Clean the filter	Raw water	Large spoon or cup, bucket
Occasionally		
- Make any necessary repairs to the filter container	Varies	Varies
Every 10-30 Years (as needed)		
- Replace the filter container	New container	See below

adapted from [9]

Never pour chlorinated water into the top of the filter. This will kill the biolayer and reduce the effectiveness of the filter.

Let's Get Technical: Filter Cleaning and Harrowing

As briefly described above, the filter should be cleaned by gently agitating only the very top (1/2 cm) of the filter material. This process re-suspends the organic matter and other contamination that has been removed from the source water over time into the standing water at the top of the filter so that it can be removed without disturbing the biolayer. Furthermore, there is no loss of the filter's function or filter media. THE BIOLAYER SHOULD NOT BE SCRAPED OR REMOVED in this type of filter as is done with traditional slow sand filters. This method, known as harrowing, involves digging or scraping into the sand and must be done with continuously operated filters in which the biolayer and oxygenated zones are much deeper. However, this process destroys the biolayer, thus impairing the filter, and should not be used in a BSF. Harrowing of a BSF may further result in decreased flow rate, anaerobic decomposition of organic matter leading to foul odor, discoloration, and poor taste and impairment of the filter to regrow a biolayer.[11]

Over a period of years, the flow rate through the filter may be decreased due to sediment embedded within the sand which is not removed by routine cleaning. In this case, it may be necessary to remove the top 5cm of sand, wash it with filtered water and replace it in the filter. This will, however, require the biolayer to be reestablished which may take several days.

Removal

	Bacteria	Virus	Protozoa	Helminth	Algae
Lab	**High** (Baumgartner et al 2007, Sobsey 2008, Stauber et al 2006)	**Mod/High** (Elliott et al 2008, Sobsey 2008, Lantagne 2007)	**High** (Palmateer et al 1999, Sobsey 2008)	**High*** (Skinner and Shaw 1998)	**None** (National Academy of Sciences 2008)
Field	**High** (Duke et al 2006, Stauber et al 2006)	-	-	**-**	-

	Fl	As	Salt	Odor & Taste	NOM	Turbidity
Lab	**None** (Skinner & Shaw 1998)	**Removal can be achieved with modifications**	**None** (National Academy of Sciences 2008)	**Moderate†** (National Academy of Sciences 2008)	**Mod/High** (Skinner & Shaw 1998)	**High** (Jenkins et al 2009)
Field	-	-	**-**	-	-	**Mod/High** (Baker et al 2006, Vanderzwaag 2009)

* No studies have been found to support this, but helminthes are generally too large to pass between the sand grains of the filter

†Chlorination may affect taste

Sources: [12], [13], [14], [15], [16], [17], [18], [19], [20], [5], [21], [22]

Longevity and Scalability

Studies have shown that the user acceptability and continued use of the BSF are strong and lasting, often reporting rates higher than other household water options. Samaritan's Purse, and organization that implements BSFs in developing countries, conducted a survey of 600 filter locations in 6 countries and found that 98.4% of BSF recipients still used their filter and 88.5% used them daily after 3 or more months since installation. In Ethiopia, 66.7% of filters were still in constant use after 5 years. A study by Fewster, Mol, and Weisent-Brandsma conducted in Kenya found that after 4 years, 97% of users were still generally satisfied with their filters and all 51 householders agreed that the filter had been a worthwhile purchase. In Haiti, 97% of filters were still working after 2.5 years, 92% were well maintained, and all 49% of users reported better water quality.[6]

Scaling of the BSF at the household level has largely been achieved by increasing the number of units on the ground. Samaritan's Purse reported constructing 65,000 filters to date in 2006 across more than 24 countries. Another organization estimates that 858,500 people are benefitting from BSFs worldwide. The production of filters can also be used to collaborate with other NGOs or create microenterprise schemes through the production of filter containers at the local level. However, the design and fabrication process of the containers limits them from being mass produced in country.[6] Finally, the BioSand method has yet to be affectively applied to large volume filters, but this has been achieved with similar continuous flow slow-sand filtration methods.

Limitations and Potential Problems

- The right types of filtration material are not readily available or are too expensive
- Irregular or improper use of the filter (such as using water that is too turbid) damages the biolayer rendering it ineffective
- The flow rate is not correctly established through washing of the sand prior to installation
- Insufficient or irregular maintenance results in poor quality water
- Too vigorous cleaning destroys the biolayer
- Smooth vertical surfaces in the filer may cause pathways through which the water can bypass the filtration layers, a process called short circuiting, which produces poorly filtered water
- Water is chlorinated before being poured into the filter

For Training Material and More Information:

A complete guide to the BSF is available from its creator, Dr. David Manz: http://manzwaterinfo.ca/index.htm

http://www.biosandfilter.org/biosandfilter/index.php/
http://www.hydraid.org

For prefabricated round molds: http://bushproof.biosandfilter.org/index.php?id=74

http://www.cawst.org/en/themes/biosand-filter

References:

1. CAWST, *Biosand Filter Manual: Design, Construction, Installation, Operation and Maintenance*. 2010, CAWST: Calgary.
2. BioSandFilter.org. *Biological Action*. 2004 [cited 2011 March 5]; Available from: http://www.biosandfilter.org/biosandfilter/index.php/item/310.
3. Manz, D.H., *Comparison: Traditional Slow Sand Filtration and BioSand Filtration*. 2008.
4. BioSandFilter.org. *Flow Rates*. 2004 [cited 2011 March 5]; Available from: http://www.biosandfilter.org/biosandfilter/index.php/item/317#ref_06.
5. Jenkins, M.W., et al., *The BioSand Filter for Improved Drinking Water Quality in High Risk Communities in the Njoro Watershed, Kenya*, F. Holley and S.L. Johnson, Editors. 2009, University of California, Davis: Davis.
6. Clasen, T., *Scaling Up Household Water Treatment Among Low-Income Populations*. 2009, World Health Organization: Geneva.
7. CAWST, *Household Water Treatment and Safe Storage Fact Sheet: Biosand Filter*.
8. Hydraid Biosand Water Filter. *Act Now!* [cited 2011 March 15]; Available from: http://hydraid.org/act/index.htm.
9. Brikké, F. and M. Bredero, *Linking Technology Choice with Operations and Maintenance in the Context of Community Water Supply and Sanitation*. 2003, World Health Organization and IRC Water and Sanitation Centre: Geneva.
10. Manz, D.H., *BSF Guidance Manual #3: Basic Operation of the Concrete BioSand Water Filter*. 2009.
11. Manz, D.H., *BSF Guidance Manual #2: Maintaining or Cleaning the Concrete BioSand Water Filter*. 2009.
12. Baumgartner, J., S. Murcott, and M. Ezzati, *Reconsidering 'appropriate technology': the effects of operating conditions on the bacterial removal performance of two household drinking-water filter systems.* Environmental Research Letters, 2007. **2**(2).
13. Sobsey, M.D., et al., *Point of Use Household Drinking Water Filtration: A Practical, Effective Solution for Providing Sustained Access to Safe Drinking Water in the Developing World.* Environmental Science & Technology, 2008. **42**: p. 4261-4267.
14. Stauber, C.E., et al., *Characterisation of the biosand filter for E. coli reductions from household drinking water under controlled laboratory and field use conditions.* Water Science and Technology, 2006. **54**(3): p. 1-7.

15. Elliott, M.A., et al., *Reductions of E-coli, echovirus type 12 and bacteriophages in an intermittently operated household-scale slow sand filter.* Water Research, 2008. **42**(10-11): p. 2662-2670.
16. Lantagne, D.S., R. Quick, and E.D. Mintz, *Household Water Treatment and Safe Storage Options in Developing Countries: A Review of Current Implementation Practices*, in *Water Stories: Expanding Opportunities in Small-Scale Water and Sanitation Projects*, M. Parker, A. Williams, and C. Youngblood, Editors. 2007, Woodrow Wilson International Center for Scholars: Washington DC. p. 17-38.
17. Palmateer, G., et al., *Toxicant and parasite challenge of Manz intermittent slow sand filter.* Environmental Toxicology, 1999. **14**(2): p. 217-225.
18. National Academy of Sciences. *Safe Drinking Water is Essential: Technologies.* 2008 [cited 2011 May 9]; Available from: http://drinking-water.org/flash/en/water.html?_3_00_00.
19. Duke, W.F., et al. *The Use and Performance of BioSand Filters in the Artibonite Valley of Haiti: A Field Study of 107 Households.* 2006; Available from: http://www.rrh.org.au/publishedarticles/article_print_570.pdf.
20. Skinner, B. and R. Shaw, *Household Water Treatment: 1.* Waterlines, 1998. **17**(2): p. 15-18.
21. Baker, D. *Project BRAVO Executive Summary.* 2006 [cited 2011 May 25]; Available from: http://www.cawst.org/assets/File/BRAVO_Executive_Summary.pdf.
22. Vanderzwaag, J.C., et al., *Field Evaluation of Long-Term Performance and Use of Biosand Filters in Posoltega, Nicaragua.* Water Quality Research Journal of Canada, 2009. **44**(2): p. 111-121.

Tools and Materials Lists

Filter Box (for cement container only):

Tools

- ☐ Steel mold
- ☐ Utility knife
- ☐ Heat source if using polyethylene tubing (propane or kerosene tank, wood fire, electric burner)
- ☐ Wire brush, sand paper, or steel wool to clean mold
- ☐ Level
- ☐ Wood shims of various sizes
- ☐ Two 9/16" wrenches
- ☐ Containers for measuring sand, gravel, and cement
- ☐ 1.5 m (5') metal rod (such as rebar) or piece of wood
- ☐ Mallet
- ☐ Trowel
- ☐ Shovels
- ☐ One 1-1/2" wrench
- ☐ Hammer
- ☐ 4 blocks of wood (about 5cm square)
- ☐ Brush

Materials

- ☐ 6 mm (¼") ID and 9 mm (3/8") OD plastic tubing (polyethylene or vinyl)
- ☐ Tape (e.g. duct tape)
- ☐ Oil (or other edible product)
- ☐ Brush or rag to apply oil
- ☐ 12 liters of cement
- ☐ 24 liters of 1 mm (0.04") sand
- ☐ 12 liters of 12 mm (½") gravel
- ☐ 12 liters of 6 mm (¼") gravel
- ☐ Water - approximately 7-10 liters
- ☐ Soap
- ☐ Face mask (optional)
- ☐ Gloves (optional)

Sand and Gravel Preparation:

Tools

- ☐ 12 mm (½") sieve
- ☐ 6 mm (¼") sieve
- ☐ 1 mm (0.04") sieve
- ☐ 0.7 mm (0.03") sieve
- ☐ Shovels
- ☐ Wheelbarrow (if available)
- ☐ Several large containers approximately 40 cm (15") deep
- ☐ Small clear container with lid

Materials

- ☐ Covers (e.g. tarps or plastic sheets), to keep the sand from getting wet and contaminated
- ☐ Clean water
- ☐ 12 mm (½") gravel
- ☐ 6 mm (¼") gravel
- ☐ 0.7 mm (0.03") sand
- ☐ Facemask
- ☐ Gloves

Metal Diffuser Box:

Tools

- ☐ Long straight edge or ruler (at least 120cm (48”))
- ☐ Tape measure
- ☐ Square or right angle
- ☐ Marker
- ☐ Metal cutters suitable for 28 gauge galvanized steel
- ☐ Drill with 3 mm (1/8”) drill bit
- ☐ Hammer
- ☐ Folding tool (e.g. bending brake) for bending 28 gauge sheet metal
- ☐ Anvil or steel plate set in a vice to hammer sheet metal against

Materials

- ☐ 1 sheet of galvanized flat sheet metal (2438 mm x 1219 mm (4’ x 8’), 28 gauge thick (0.46 mm or 0.018”))

Filter Installation:

Tools

- ☐ Tape measure
- ☐ A stick [approximately 100 cm (40”) long, 2.5 cm x 5 cm (1” x 2”) is preferred]
- ☐ Diffuser
- ☐ Storage container
- ☐ Watch
- ☐ Measuring container with 1 liter mark
- ☐ 1 m (3’) of hose that just fits over the outlet tube
- ☐ Hose clamp (if available)
- ☐ Funnel (can be made from the top of a pop or water bottle)

Materials

- ☐ Approximately 3 liters of washed 12mm (½”) gravel (drainage layer)
- ☐ Approximately 3¼ liters of washed 6mm (¼”) gravel (separating layer)
- ☐ Approximately 25 liters of washed 0.7mm (0.03”) sand
- ☐ 40-80 liters (10-20 gallons) of water
- ☐ Chlorine

Chemical

Chemicals are often used for water treatment in the developing world because of their low cost and high effectiveness. Chemicals can be used for coagulation and flocculation, adsorption, ion exchange, or disinfection. However there are many factors that affect the success of these chemicals including concentration, contact time, pH and temperature.

The most common chemical disinfectant is chlorine. Chlorine is an inexpensive oxidant that is effective against bacteria and viruses, but not Giardia or Cryptosporidium. Chlorination is relatively simple, is inexpensive, and can be easily scaled. It may be added in a number of forms, either directly as a liquid or gas, or as sodium or calcium hypochlorite. The US Centers for Disease Control advocate the use of sodium hypochlorite as a part of the Safe Water System. Chlorination also provides residual protection but may produce harmful byproducts in the presence of organic material.

Chloramines are the combination of chlorine and ammonia. They are powerful against bacteria and are generally more stable and longer lasting than other forms of chlorination, which may be helpful in waters that are stored for long periods of time or are transported over great distances. Chloramines are inexpensive and also produce less of an adverse taste than chlorination. However the production and use of chloramines requires a skilled operator.

Iodine is another common disinfectant. It is commonly available in tablet form or as an ion exchange resin. Ion exchange resins work by exchanging the harmful charged particles in source water with harmless ones on the resin's surface. The iodine resin contains forms of iodine that are stronger antimicrobial agents than tablets, but their contact time in small point-of-use applications is low and the amount of iodine released is difficult to control. This is dangerous because, as with most chemicals, too much can be damaging to health and too little will be ineffective in treating pathogens. Too much iodine also causes a foul taste. Iodine is effective for bacteria but has limited effect on enteric viruses.

Ozone is another powerful oxidant that is effective against bacteria, viruses, giardia, cryptosporidium, organic chemicals and some common inorganic chemicals such as iron and manganese. Ozone (O_3) is an unstable form of pure oxygen that does not affect taste or odor, but would be difficult to produce and store in a developing world setting. Furthermore, ozone does not provide residual treatment and can produce bromated which is harmful to human health.

Alum and iron salts are used as coagulants and flocculants which remove microbes by removing the suspended particles they are often attached to. These chemicals agglomerate suspended particles into larger masses which settle or can be filtered from the water. However use of these chemicals requires a degree of skill and technical competence that makes them less applicable for household use.

Activated carbon, also known as activated charcoal, is a form of carbon that is highly porous and thus has a large surface area for adsorption. Activated carbon is available both granular and powdered, the difference between which is only the size of the particles. Activated carbon is used most often in columns or beds and is known to remove both contaminants and most organic material which makes it especially useful for treating taste and color problems. However, both forms of activated carbon can be very expensive if used on a continual basis.

The Pureit water system produced by Unilever is a more advanced option for chemical treatment. This system is a family sized pitcher-like device that contains both activated carbon and chlorine treatment stages. It also uses a microfiber filter to remove visible particles and a clarifier which removes the chlorine at the point of consumption. The Pureit systems range in size from 14 to 23 liters and US$22 to $71 in cost.

PUR Packets

PUR Packets are produced by Procter & Gamble (P&G) and are the result of a collaboration with the Center for Disease Control in response to the cholera outbreaks in Latin America in the early 1990s. Now headed by Dr. Greg Allgood under the Children's Safe Drinking Water Program, more than 16 million packets have been distributed around the world in developing countries and disaster relief settings.[1] The PUR packets improve upon the traditional disinfection method of chlorine bleach by adding a turbidity removal agent.

How it works

PUR packets work by two mechanisms: chemical treatment and coagulation. The active chemicals in PUR Packets are calcium hypochlorite and ferric sulfate. The ferric sulfate acts as a particle binder which causes dirt and other suspended particles to clump together and settle out of the water.

Let's Get Technical: Ferric Sulfate and Flocculation

When particles are 0.1 µm or smaller in size, the electrostatic charge (usually negative) on the particles causes them to repel one another and remain suspended in water. This causes turbidity in water which can harbor pathogens and reduce the effectiveness of water treatment devices. For example, when chlorine is present it rapidly binds to organic matter leaving little chlorine available to kill pathogens, and potentially producing harmful byproducts. For this reason, a flocculant is needed to allow the calcium hypochlorite in the packets to do its job.[2]

Ferric sulfate is an iron salt widely used as a coagulant and flocculant in wastewater treatment. Flocculants are often positively charged particles which interact with these small negatively charged particles and allow them to aggregate, forming "flocs". When the flocs become large enough their weight causes them to sink, removing the particles from the water. Ferric sulfate is also capable of removing heavy metals such as arsenic, chromium, and lead.

Calcium hypochlorite, $Ca(ClO)_2$, is the disinfecting agent in the product and kills a wide range of pathogens. The large granules in the PUR packet allow the chlorine to be released slowly over time to maintain chlorine residual.[3] When the PUR packet is stirred into water, the two chemicals work to disinfect the water and remove the suspended particles. After only a few minutes the water will have been disinfected and the flocs will have settled, forming a layer of dirt on the bottom of the container. The clean water can be poured through a cloth to separate the flocs and drunk immediately.

$Ca(ClO)_2$ and $Fe_2(SO_4)_3$ are corrosive to eyes and skin and can be harmful if swallowed or inhaled.

Let's Get Technical: Calcium Hypochlorite

Calcium hypochlorite works in much the same way as liquid chlorine bleach (sodium hypochlorite). When granular calcium hypochlorite is dissolved in water it forms hypochlorous acid and calcium hydroxide. Hypochlorous acid provides chlorine, which is a powerful oxidant that acts as a biocide. However, the calcium hypochlorite has much more available chlorine than sodium hypochlorite. In studies it has shown to have a longer residual than contact chlorine applications.[4] Calcium hypochlorite is also very stable and readily available in stores as "pool shock" used to disinfect swimming pools. However, the calcium hydroxide byproduct can affect the hardness of the water and therefore user acceptability.[5]

When to use it

- When communities or households cannot maintain a filter or treatment system
- When water is highly turbid
- When arsenic is present in the water

When not to use it

- When a constant (and usually subsidized) source of packets is unavailable
- Where use of chemicals is unsafe or unacceptable to users
- When there are dissolved chemicals or cryptosporidium in the water

User Acceptability

Pros
- No long term commitment
- Low initial cost
- Visible treatment process

Cons
- Perception of complicated preparation
- High recurring cost
- Residual chlorine smell and taste

Materials and Installation

No installation is required for the use of PUR Packets.

Materials include:

- ☐ a pair of scissors
- ☐ a large stirring device
- ☐ 2 10 liter containers, one for mixing and the other for storage
- ☐ a cotton filtering cloth

Your storage vessel needs:

- A narrow mouth
- A cap
- A handle
- To be lightweight and durable
- To hold at least 10L of water

Cost: $$

One advantage of using PUR packets is that no initial investment is required. However, the packets have a high recurring cost of approximately US$o.10 per 10 liters (depending on location), which is much higher than the fraction of a cent per liter cost of most other treatment methods.[6] For a household that uses 20 liters per day, this is a cost of $73 annually.

Training

Actors	Roles	Skills Required
Family member	Carefully add packet contents, stir and filter water, clean storage container	
External support	Train users on proper treatment methods and chemical handling, ensure continued use	
☺ Simple, often requires awareness raising or training Level of technical skill required		

Use

P&G provides easy to follow instructions for the use of PUR Packets:

1. Open a sachet using a pair of scissors.
2. Add the contents of the sachet to a clean mixing vessel containing 10 liters of water.
3. Agitate the powder vigorously in the water for 5 minutes. Be sure a vortex is created when mixing. Then, let the water stand until it clarifies.
4. After adding the powder to the water, the water will become colored. The color indicates that the product is working. When the process is finished, the water will be crystal clear.
5. If you see the water is still colored, you can mix again and let it rest for another few minutes.
6. Once the water looks clear, and the floc is at the bottom of the bucket, filter the water through a clean cloth filter into a clean storage container and cover it with a lid.
7. The filter must be a cotton cloth that prevents the floc from passing through.
8. Wait 20 minutes before drinking the water.
9. Do not drink water if it is colored or cloudy after treatment. If the floc accidentally gets into the treated water, use another cloth to filter the floc out of the treated water. The water is still good to drink.
10. Always dispense the water from the storage container into another container, such as a cup or glass for drinking.
11. Discard the floc from the water treatment process in the latrine, or on the ground away from children and animals.

Operations and Maintenance

Activity and Frequency	Materials and Spare Parts	Tools and Equipment
Daily		
- **Clean storage container and filter cloth**	Soap, water	Brush
Occasionally		
- **Replace a damaged storage container**	New container	

Removal

	Bacteria	Virus	Protozoa	Helminths	Arsenic
Lab	**High** (Souter et al 2003, P&G)	**High** (Souter et al 2003, P&G)	**High** (Souter et al 2003, CAWST 2009) Removal is moderate to high for C. parvum (WHO GDWQ 2008, P&G, Souter et al 2003)	**High** (CAWST 2009)	**High** (Souter et al 2003, P&G)
Field	**High (including cyanobacteria)** (Souter et al 2003, Allen et al 2004)	**High** (Souter et al 2003, Le et al 2003)	**High** (Souter et al 2003) Removal is moderate for C. parvum (Crump et al 2004)	-	**High** (Souter et al 2003, Norton et al 2003a)

	Odor & Taste	NOM	Turbidity	Residual	Diarrheal Morbidity Reduction
Lab	-	**High** (P&G)	**High** (CAWST 2009)	**Yes** (Souter et al 2003, McLennan et al 2009)	-
Field	**Medium†** (CAWST 2009)	-	**High** (Norton et al 2003b, P&G, Crump et al 2004)	**Yes** (Norton et al 2003b, Le et al 2003, Crump et al 2004, Doocy et al 2006,)	**Moderate to High** (P&G, Crump et al 2005, Doocy et al 2006, Luby et al 2006, Reller et al 2003)

Sources: [7], [8], [9], [10], [11], [12], [2], [13], [14], [4], [15], [16], [17]

Longevity and Scalability

The longevity of a single packet is a day's worth of water or less. The chemicals in the PUR packet have a shelf life of approximately one year. The scalability of flocculant-disinfectant treatment using PUR packets is limited by the number of packets available to users. However, unless packets are provided at a subsidized cost or free of charge, it is unlikely that users will desire or be able to afford to treat greater volumes of water.[18] It is possible that the same chemical formulation found in the packets be used in a community sized water treatment system (as these chemicals were already routinely used for this purpose in the developed world), however the cost of construction and operation of such a system would be prohibitively high. Thus scaling up is possible but severely limited by cost.

Limitations and Potential Problems

- Users may attempt to use partial packets or the incorrect amount of water
- Users may use the product inconsistently due to cost or other factors, reducing the health benefits
- Users may only use the water treated with PUR packets for certain members of the household (elderly and infants who are sick)[6]

For Training Material and More Information:

http://www.csdw.com/csdw/home.shtml

http://www.pghsi.com/pghsi/safewater/development.html

References:

1. Lantagne, D.S., R. Quick, and E.D. Mintz, *Household Water Treatment and Safe Storage Options in Developing Countries: A Review of Current Implementation Practices*, in *Water Stories: Expanding Opportunities in Small-Scale Water and Sanitation Projects*, M. Parker, A. Williams, and C. Youngblood, Editors. 2007, Woodrow Wilson International Center for Scholars: Washington DC. p. 17-38.
2. Crump, J.A., et al., *Effect of point-of-use disinfection, flocculation and combined flocculation-disinfection on drinking water quality in western Kenya*. Journal of Applied Microbiology, 2004. **97**(1): p. 225-231.
3. Lougheed, T., *A Clear Solution for Dirty Water*. Environmental Health Perspectives, 2006. **114**(7): p. A424-A427.
4. McLennan, S.D., L.A. Peterson, and J.B. Rose, *Comparison of Point-of-Use Technologies for Emergency Disinfection of Sewage-Contaminated Drinking Water*. Applied and Environmental Microbiology, 2009. **75**(22): p. 7283-7286.
5. Arch Chemicals. *Calcium Hypochlorite*. 2008 [cited 2011 May 18]; Available from: http://www.archchemicals.com/Fed/Corporate/Docs/ACC/ARCH_CHEMICALS-Calcium_Hypochlorite.pdf.
6. Harris, J., *Challenges to the Commercial Viability of Point-of-Use (POU) Water Treatment Systems in Low-Income Settings*, in *Water Science Policy and Management*. 2005, Oxford University. p. 78.
7. Souter, P.F., et al., *Evaluation of a new water treatment for point-of-use household applications to remove microorganisms and arsenic from drinking water*. Journal of Water and Health, 2003. **1**(2): p. 73-84.
8. Procter & Gamble. *P&G's PUR Purifier of Water*. Available from: http://www.pghsi.com/pghsi/safewater/pdf/International_PPOW_handout.pdf.
9. CAWST. *Household Water Treatment and Safe Storage Fact Sheet: PUR Packets*. 2009; Available from: http://www.cawst.org/en/resources/pubs/category/25-fact-sheets-academic.
10. World Health Organization, *Guidelines for Drinking-water Quality: Third Edition, Incorporating the First and Second Addenda, Volume 1: Recommendations*. 2008, WHO Press: Geneva.
11. Allen, E.A.D., W.W. Carmichael, and B. Keswick, *The Evaluation of a Flocculating Agent (PUR) for the Removal of Cyanobacteria and their Toxins from Potable Water Supplies*, in *Sixth International Conference on Toxic Cyanobacteria*. 2004: Bergen, Norway.
12. Le, B.T., J.G. Jacangelo, and K.J. Schwab, *Viral Inactivation In Surface Water Using A Metal Coagulant Combined With Granular Slow-Release Chlorine*, in *American Society for Microbiology* 2003: Baltimore.

13. Norton, D.M., et al., *Field Trial of a Flocculent-Disinfectant Point-of-Use Water Treatment for Improving the Quality and Microbial Safety of Surface Pond Water in Bangladesh*, in *10th Asian Conference on Diarrhoeal Diseases and Nurtition*. 2003: Dhaka, Bangladesh.
14. Norton, D.M., et al., *A Combined Flocculent-Disinfectant Point-of-Use Water Treatment Strategy for Reducing Arsenic Exposure in Rural Bangladesh*, in *10th Asian Conference on Diarrhoeal Diseases and Nurtition*. 2003: Dhaka, Bangladesh.
15. Doocy, S. and G. Burnham, *Point-of-use water treatment and diarrhoea reduction in the emergency context: an effectiveness trial in Liberia.* Tropical Medicine & International Health, 2006. **11**(10): p. 1542-1552.
16. Luby, S.P., et al., *Combining drinking water treatment and hand washing for diarrhoea prevention, a cluster randomised controlled trial.* Tropical Medicine & International Health, 2006. **11**(4): p. 479-489.
17. Reller, M.E., et al., *A randomized controlled trial of household-based flocculant-disinfectant drinking water treatment for diarrhea prevention in rural guatemala.* American Journal of Tropical Medicine and Hygiene, 2003. **69**(4): p. 411-419.
18. Luby, S.P., et al., *Difficulties in Bringing Point-of-Use Water Treatment to Scale in Rural Guatemala.* American Journal of Tropical Medicine and Hygiene, 2008. **78**(3): p. 382-387.

Membrane

In recent years, membranes have taken on a larger role in developing world water treatment. Cost has been their greatest limiting factor thus far, but their precision in removal of pathogens makes them attractive.

In membrane treatment water is passed through a thin material with highly controlled pore sizes. As water passes through the pores, contaminants are removed from the water by size exclusion, charge repulsion, and differential permeation. The material and size of the pores determines the removal capabilities of the membrane. The most common classifications of pore size are microfiltration ($\geq 0.1\mu m$), ultrafiltration ($\geq 0.01\mu m$), nanofiltration ($\geq 0.001\mu m$), and reverse osmosis ($\geq 0.0001\mu m$).

There are several membrane technologies that have been adapted for use in developing world applications. LifeStraw and LifeStraw Family are two products produced by Swiss company Vestergaard Frandsen. The LifeStraw products use a small, portable ultrafiltration membrane. The Lifesaver Jerrycan also uses an ultrafiltration membrane in a 18.5 liter portable plastic container. The Lifesaver Bottle uses activated carbon in addition to an ultrafiltration membrane in a 750mL personal water bottle.

The Sky Juice Foundation offers more advanced options for membrane filtration. These products are designed to serve communities or refugee camps in emergency situations, but are more difficult to set up and maintain. The Sky Hydrant is portable and can process up to 1,000 liters of water per hour through an ultrafiltration membrane. The Sky Hydrants can be combined into a Sky Station for a larger, longer term solution.

LifeStraw Family

LifeStraw Family is a point of use water treatment device that works by membrane filtration. It is a gravity fed hollow fiber ultrafiltration membrane that is backwashable to allow for easy maintenance and extended life of the filter and requires no external chemicals or power source. It treats 2.5 liters at a time and is designed to treat 18,000 liters over its lifetime, enough water for a family of five for about five years [1]. The LifeStraw Family is produced by Swiss company Vestergaard Frandsen.

How it works

LifeStraw Family uses a series of membranes and filters of different sizes to remove dirt and pathogens from water. First, dirty source water is poured into the prefilter where coarse particles larger than 80μm are removed. After passing through the prefilter, the water moves into the halogen chamber. The halogen chamber adds a small dose of active chlorine to the water which serves a dual purpose. First, the chlorine acts as a powerful oxidant and thus disinfectant in the water, killing some of the pathogens. For this reason, the chlorine also helps to maintain the membrane by slowing biofilm growth which clogs the pores and reduces the membrane's effectiveness [2].

As a result of gravity, the water flowing into the membrane cartridge reaches 0.1 bar pressure which forces it through the membrane. The membrane cartridge contains an ultrafiltration membrane of 20 nm (0.02μm) porosity. The membrane removes any particles larger than 20 nm, including turbidity, algae, protozoa cysts and most bacteria and viruses (see callout below) [2].

Let's Get Technical: Membrane Size and Removal Properties

Table 1 Major Membrane Filtration Processes Used in Drinking Water Treatment

Type	Pore Size[a] (μm)	Primary Applications	Microbes Removed
Microfiltration	≥0.1	Removal of particles and turbidity	Algae, protozoa, and most bacteria
Ultrafiltration	≥0.01	Removal of dissolved nonionic solutes	Algae, protozoa, and most bacteria and viruses
Nanofiltration	≥0.001	Removal of divalent ions (softening) and dissolved organic matter	Algae, protozoa, and most bacteria and viruses
Reverse Osmosis	≥0.0001	Removal of monovalent ions (desalination)	Algae, protozoa, and most bacteria and viruses

a Pore size is sometimes described as molecular weight cut-off, which is the degree of exclusion of a known solute, determined under a given set of test conditions in the laboratory.

Source: adapted from [3]

Let's Get Technical: The Membrane

The ultrafiltration membrane in the LifeStraw Family is a made from a Polyethersulfone (PES) resin called Ultrason E 6020 P manufactured by BASF. PES is a hydrophilic material that wets quickly resulting in less fouling, a higher flow rate and greater throughputs. It is heat resistant, strong, and acid and base resistant. It also has a highly controlled pore size which improves its filtration capability.[4]

When to use it

- When water has unknown microbial quality or is highly turbid

When not to use it

- When the product cannot be supplied free of charge or at a subsidized cost
- When salinity is a major concern

User Acceptability

Pros
- No chemicals used
- No batteries or replacement parts

Cons
- Cleaning can be complicated and time consuming
- Cost

Materials and Installation

No additional materials are required for installation of the LifeStraw Family. The unit should be hung in the home or other protected area in the community so that gravity can effectively pull water through the membrane.

Cost: $$

The initial cost of the LifeStraw family may be prohibitively expensive in most low income settings, which is the primary criticism against its use. Vestergaard Frandsen sells the units in bulk to development agencies for about US$20 [1]. However, assuming the unit serves five people for five years this is less than $1 per person per year or $0.001 per liter for the estimated 18,000 liters the filter will treat. There is no operation cost for the LifeStraw Family.

Training

Actors	Roles	Skills Required
Family member	Use the filter, clean the filter	
External support	Train users in correct usage and cleaning procedure	

☺ Simple, often requires awareness raising or training
Level of technical skill required

① **Feed water bucket with prefilter**
2L capacity container for filling with unpurified water
② **Prefilter**
the 80 micron prefilter removes coarser turbidity and is easy to clean
③ **Halogen chamber**
releases low-level chlorine to prevent membrane fouling
④ **Plastic hose (one metre long)**
gravity creates sufficient pressure on the membrane cartridge in order to reach a high flow rate
⑤ **Membrane cartridge**
ultra filtration takes place in the membrane cartridge – a pore size of 20 nanometre retains bacteria, viruses, parasites and fine dirt particles
⑥ **Blue tap**
outlet for purified water
⑦ **Cleaning bulb**
backwashing of the membranes is done by squeezing the bulb three times
⑧ **Exit valve**
disposes the dirt and impurities

Use

Water from the red tap should never be drunk

The first time the LifeSaver Family is used, the membrane must be prepared. Opening the exit valve for 5 seconds allows the air trapped in the membrane to escape and the membrane fibers to be moistened. For daily use, the dark blue filter container should be mounted to the wall or hung vertically. Close the light blue tap (6) and the red exit tap (8) on the membrane cartridge. Fill the dark blue filter container with water and open the red exit valve for 30 seconds. The water from the red tap should not be drunk. Collect water from the light blue tap. This water is clean and safe to drink.

Operations and Maintenance

Activity and Frequency	Materials and Spare Parts	Tools and Equipment
Daily		
- Clean the prefilter		Basin, water
- Clean the membrane cartridge		Water
Every 3-5 years		
- Replace the LifeStraw Family		

Both filters of the LifeStraw Family should be cleaned daily. First, the prefilter should be removed from the dark blue container and washed to remove all the trapped dirt. After washing, the prefilter should be replaced. Next the membrane cartridge should be cleaned. Both the red and light blue valves must be closed and the dark blue prefilter filled with water. The red valve must then be opened and the water allowed to flow from the valve for 30 seconds before closing again it. Then, the membrane should be backwashed by squeezing the red cleaning bulb. After 30 seconds the bulb will fill again and the process should be repeated twice. Finally all the dirty water must be release from the membrane cartridge by opening the red exit valve for 30 seconds then closing it again.

Never use a sharp object to clean the prefilter

Let's Get Technical: Membrane Fouling and Backwashing

Membrane fouling is the clogging or blocking of the membranes pores by the particles which are not allowed to pass through the pores. Fouling occurs in several ways. Particles can clog the pores either within the pore itself or at the mouth of the pore. The cake layer of rejected material can also block the pore by covering it.

When the pores of the membrane become fouled, the removal efficiency is deteriorated and the flow rate through the membrane decreases. In order to maintain the life of the membrane the fouling particles must be removed. In many large scale membrane applications, the membranes must be scoured with chemicals to remove the ingrained particles. In the LifeStraw Family this is done by backwashing alone, preventing the need and expense for harsh chemicals.

Removal

	Bacteria	Virus	Protozoa	Helminth	Salt	Turbidity
Lab	**High** Meets EPA 6-4-3 Standard (Clasen 2009, Vestergaard Frandsen, Intertek Vietnam, CDC 2008)	**High** Meets EPA 6-4-3 Standard (Clasen 2009, Vestergaard Frandsen, Intertek Vietnam, CDC 2008)	**High** Meets EPA 6-4-3 Standard (Clasen 2009, Vestergaard Frandsen, Intertek Vietnam)	**High** (Sobsey 2002, Vestsergaard Frandsen)	**None** (LeChevallier 2004)	**High** (Vestergaard Frandsen, no data provided)
Field	**High** (Boisson 2010, CDC)					**High** (Institute of Technology of Cambodia)

Sources: [1], [2], [5], [6], [3], [7]

Longevity and Scalability

Because the membrane technology in the LifeStraw Family is a contained unit, scaling of the technology requires an increase in the number of units. The largest impediment to scaling is likely the cost. However due to the high reported rates of acceptance scaling up the use of the LifeStraw is possible.

Limitations and Potential Problems

- Users may confuse the cleaning process or drink from the wrong valve
- Users are advised not to store the filtered water which forces children to drink unfiltered water when parents are away

For Training Material and More Information:

http://www.vestergaard-frandsen.com/lifestraw

References:

1. Clasen, T., et al., *Laboratory Assessment of a Gravity-Fed Ultrafiltration Water Treatment Device Designed for Household Use in Low-Income Settings.* American Journal of Tropical Medicine and Hygiene, 2009. **80**(5): p. 819-823.
2. Vestergaard Frandsen. *LifeStraw Brochure.* [cited 2011 May 25]; Available from: http://www.vestergaard-frandsen.com/component/docman/cat_view/51-product-brochures/57-lifestrawr?orderby=dmdate_published&ascdesc=DESC.
3. LeChevallier, M.W. and K.-K. Au, *Water Treatment and Pathogen Control: Process Efficiency in Achieving Safe Drinking Water.* 2004, World Health Organization: London.
4. BASF. *Filter membrane made of high performance plastic Ultrason for water treatment.* 2011 [cited 2011 June 2]; Available from: http://www.basf.com/group/pressrelease/P-09-305.
5. Centers for Disease Control. *Drinking Water Treatment Technologies for Household Use.* 2008 [cited 2011 2011]; February 17]. Available from: http://www.cdc.gov/healthywater/pdf/drinking/Household_Water_Treatment.pdf.
6. Sobsey, M.D., *Managing Water in the Home: Accelerated Health Gains from Improved Water Supply.* 2002, World Health Organization: Geneva.
7. Boisson, S., et al., *Field Assessment of a Novel Household-Based Water Filtration Device: A Randomised, Placebo-Controlled Trial in the Democratic Republic of Congo.* PLoS One, 2010. **5**(9).

APPENDIX B

WATER RELATED ILLNESSES

B.1 Contamination Routes

Water related illnesses are classified by their broad mode of transmission. The Bradley system defines four non-mutually exclusive categories:

- Water-borne: caused through consumption of water contaminated with human or animal excreta or urine containing pathogenic bacteria or viruses (i.e. cholera, typhoid, amoebic and bacillary dysentery, and other diarrheal diseases)
- Water-washed: caused through the use of inadequate volumes for personal hygiene
- Water-based: where an intermediate aquatic host is required (i.e. dracunculiasis, schistosomiasis, and some other helminths)
- Water-related vector: spread through insect vectors associated with water (i.e. dengue fever, lymphatic filariasis, malaria, onchocerciasis, and yellow fever) [41],[88]

This system is valuable because it focuses on the impact of different interventions. But, diseases may fall into more than one category, such as guinea worm which is both a water-based and a water-borne disease [44]. Others have suggested that the water-borne category should be replaced with "Fecal-Oral" to reflect the multiple transmission pathways and to reduce the water-washed category to skin and eye infections that are affected by the water volumes used for hygiene [89]. Other related categories include:

- Excreta related: caused by direct or indirect contact with fecal pathogens or vectors (i.e. trachoma and most waterborne diseases)
- Water collection and storage: caused by contamination during or after water collection, often due to improperly designed or cleaned containers
- Toxin-related: caused by toxic bacteria, such as cyanobacteria, which are associated with eutrophication and cause gastrointestinal and hepatic illnesses.[41]

Figure B.1 below describes the exposure pathways for many water related illnesses.

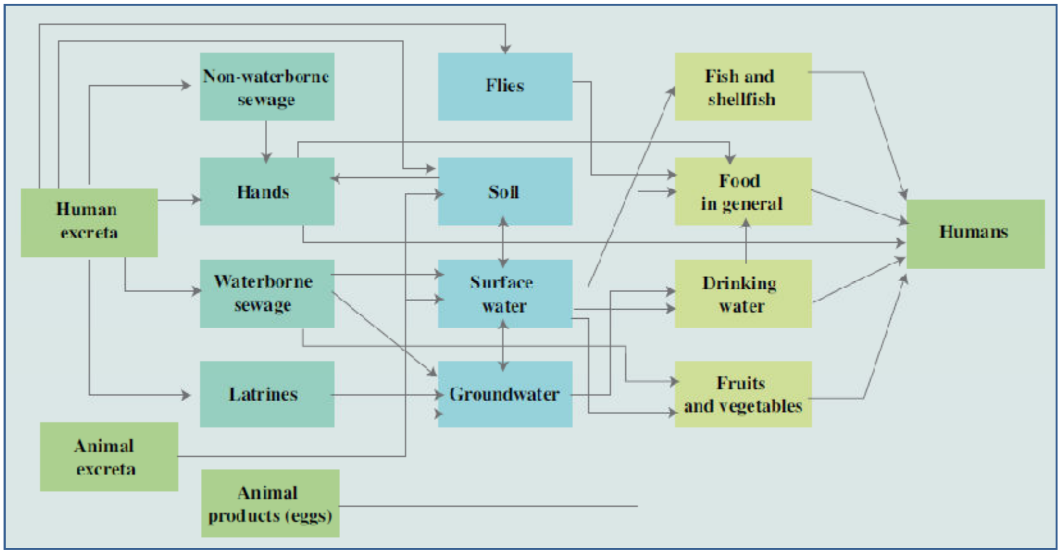


Figure B.1 Exposure Pathways for Water Related Illness [64]

B.2 Diseases Associated with Water

In order to understand the correlation between water and health it is important to know the direct outcomes of poor water on health. In order to prevent these outcomes or to design water systems that address them, it is essential to understand their exposure routes and mechanisms of infection. Listed below are some of those diseases most strongly connected to water, their mechanisms, and the demographics which they most often affect.

B.2.1 Ascariasis

Ascariasis is a water-based disease caused by the Ascaris lumbricoices roundworm. The exposure pathway begins when humans consume uncooked food contaminated by eggs of the worm, either directly through human contact or through soil containing eggs. In the intestines, the eggs hatch and grow into larvae which then penetrate the intestines and travel through the blood stream to the lungs. From there the larvae reach the throat and are eventually swallowed again, returning to the intestines where they develop into adult worms up to 30cm in length. Female worms then lay eggs which pass into feces and exit the body to begin the cycle again. Eggs become infective after two to three weeks and may remain so for several months or years [90].

Children are more often infected than adults. First infections usually occur at three to eight years of age and many times are the result of playing in infected soil and subsequently putting their hands in their mouths. Consuming food grown in contaminated soil or watered with inadequately treated wastewater is another possible route. The first sign of infection is usually the passage of a worm but intestinal blockages may occur in more severe infections in small children, causing abdominal pain [90].

Ascariasis is one of the most common human parasitic infections and is found worldwide, although infection is most common in tropical and subtropical regions. More than 10% of the developing world is infected with intestinal worms at any given time, and a large percentage of those results in Ascariasis. Even though the disease is treatable, 60,000 lives are lost annually, most of which are children. The disease can be prevented with proper sanitation and hygiene, treatment of drinking water, avoiding soil contact, and cooking all raw fruits and vegetables [90].

B.2.2 Dengue and Dengue Hemorrhagic Fever

Dengue is a water-related vector infection which has risen as a major international public health concern in recent years, affecting up to 100 million people annually. Dengue fever causes a severe flu-like illness in infants, young children, and adults, but rarely leads to death. The more severe Dengue Hemorrhagic Fever (DHF) is potentially fatal, and is now the leading cause of childhood mortality in many Asian countries. Prevalence of dengue has grown significantly in recent years and is now found in more than 100 countries worldwide [91].

Dengue is caused by one of four viruses. A person can only be infected with each virus once, but may still be susceptible to the others after recovery. A secondary infection may also increase the risk of DHF. The transmission cycle of Dengue begins with the bite of an infected female Aedes mosquito. Once infected, a person may experience a range of symptoms, depending on their age. Fever and rash are common in infants and young children. Older children and adults may have either a mild fever, or a sudden high fever, headache, pain behind the eyes, muscle and joint pain, and a rash. DHF is characterized by high fever, enlargement of the liver, or circulatory failure [91].

Unfortunately, no vaccination against dengue is currently available. Prevention is most effectively achieved through the control of mosquitoes, largely through elimination of standing water areas that serve as breeding sites. Other measures include mosquito screens, protective clothing, and widespread use of insecticides [91].

B.2.3 Diarrheal Disease

Diarrheal diseases are water-borne illnesses caused by the ingestion of pathogens through drinking water, contaminated food, or unclean hands. This category includes many serious diseases including cholera, and dysentery. Eighty-eight percent of the diarrheal cases worldwide can be attributed to unsafe water, inadequate sanitation or poor hygiene resulting in 2 billion illnesses and up to 2.2 million deaths annually. 1.5 million of these are children under the age of five and represent 15% of all deaths among children in this age group [19], [39], [44].

Diarrhea is a primary symptom of gastrointestinal infection. It may last days or weeks and can be life threatening if the individual becomes dehydrated, especially if their immune system is already impaired. Children and the elderly are particularly at risk. Repeated cases can also lead to malnutrition [92].

Diarrheal diseases are spread by bacteria, viruses, and other parasitic organisms which may all be spread through contaminated drinking water. It is common where water for hygienic practices is limited or where these are not routine. Contamination may originate from infiltration of wastewater or contaminated groundwater into the drinking water supply, person to person contact, or food grown or washed with insufficiently treated water [92].

B.2.4 Dracunculiasis (Guinea Worm disease)

This is a painful infection caused by a large nematode, also called a Guinea Worm. It begins when a water flea ingests the larvae of the nematode and becomes infected after a two week period. When the water fleas are ingested by humans, gastric acid dissolves the flea and activates the larvae which then penetrate the lining of the stomach. As the worm develops, it travels through the subcutaneous tissue. After about a year a blister forms as the adult 1 meter long worm attempts to emerge, causing itching, swelling, burning, and fever. The infected person often seeks relief by submerging the blister in water, such as in a lake or stream, which stimulates the worm to emerge and release thousands of larvae into the water beginning the cycle again. The extraction is a slow and painful process, often taking weeks. For people in remote areas with limited or no access to health care, ulcers can take several weeks to heal and may be complicated by bacterial infections, stiff joints, arthritis, and even permanent limb paralysis [93], [94].

At the beginning of the 20th century, Guinea Worm disease affected nearly 50 million people in Africa and Asia. As of 2009, the disease had been reduced by more than 99%. Thanks to concentrated efforts of endemic countries and the international community there were less than 3,200 reported cases. These were limited to Sudan, Ethiopia, Ghana, and Mali. Guinea worm is only known to affect humans and its prevention requires clean drinking water sources and the prevention of infected persons from entering water sources with an active ulcer. Currently, Dracunculiasis is set to be the second disease in human history to be completely eradicated and the first to do so without vaccination or medical treatment [95].

B.2.5 Hepatitis

Hepatitis is a disease which affects the liver, causing damage or cancer. Hepatitis A and E, two infectious forms of Hepatitis, are water-borne diseases spread through the fecal-oral route. They are often the result of insufficient water supplies or inadequate sanitation and hygiene [96]. They are highly excreted and can survive outside of the body for long periods of time allowing them to be highly contagious [97].

These illnesses may exhibit a range of symptoms. They usually start with abrupt fever onset, weakness, loss of appetite, nausea, and abdominal discomfort, followed by jaundice. Infection may last weeks or several months [96]. In nearly all developing countries, children become infected with Hepatitis A before the age of 9. However, many of these cases are asymptomatic and therefore undiagnosed [97]. Fortunately, most patients recover completely with no long-term side effects [96].

Both Hepatitis A and E are endemic worldwide. They are particularly common in developing areas with poor sanitary and hygiene conditions or in industrializing nations with poor sanitary regulations. There are no specific drugs to treat hepatitis A or E, so ensuring adequate water supply and proper sanitation is the best control measure against these diseases [96].

B.2.6 Japanese Enchephalitis

Japanese Encephalitis (JE) is a water-related vector disease which causes inflammation of the membranes surrounding the brain. The disease is caused by a flavivirus carried by the Culex tritaeniorhynchus and Culex vishnui species of mosquito which commonly breed in flooded rice patties. JE is largely a zoonotic disease: Egrets and Herons are the primary victims and the mosquito vectors are normally zoophilic (they primarily feed on the blood of animals). However, the disease may be transferred to humans during an overpopulation, and in turn increased biting rate, of mosquitoes [98].

JE infection in humans is usually mild but approximately 0.5% of cases become severe and may lead to permanent damage to the central nervous system or death. Infection primarily occurs in young children because older children and adults have become immune through a previous infection. JE has largely spread in South and South-East Asia in the last 20 years due to the expansion of irrigated rice production. Outbreaks have occurred in a number of places, including India and Sri Lanka [98].

Vaccination against JE is available. Unfortunately, it is a three stage process that is often unavailable in areas with limited health services. Another inexpensive vaccine is available in China only. Because of the extent of irrigated rice patties in Asia, insecticide use against the mosquito vector is impractical. Partial drying of the fields may be used.

Elimination of swine populations in areas of outbreak is also common, as pigs are amplifying carriers of the disease [98].

B.2.7 Lymphatic Filariasis

Also known as Elephantiasis, Lymphatic Filariasis (LF) is a debilitating disease and the leading cause of permanent and long term disability worldwide [99]. It is a water-related vector disease carried by mosquitoes. The infection cycle begins when mosquitoes bite infected humans and ingest the threadlike parasitic filarial worms that cause the disease. Inside the mosquito, the microfilariae become infective after one to three weeks and then travel to the mosquito's probiscus where they are transferred to a human through a mosquito bite. Once in their new human host, the microfilariae invade the lymphatic system where they live four to six years, multiplying into millions of immature microfilaria that circulate through the blood [100]. The microfilariae form nests within the lymphatic system and cause blockages which limit the body's ability to regulate the flow of fluid between the blood and tissues. As a result, patients suffer gross enlargement of the legs, arms, and genitals as well as kidney and lymphatic damage [99].

LF is most predominant in tropical and subtropical areas and has been present in more than 80 countries. Over 120 million people worldwide have been infected, including 40 million who have been seriously incapacitated. More than a third of these people live in India, and another third in Africa with the remainder spread over South Asia, the Pacific and the Americas. Severe symptoms appear most often in adults, and in endemic areas 10% of women and up to 50% of men may be infected [100]. Dual prescription treatments have proved effective in treating and reducing the spread of LF, leading it to be listed as one of several parasitic diseases which has the potential to be completely eradicated [99].

B.2.8 Malaria

The world's most important parasitic disease, malaria is a water-related vector disease. The single-celled plasmodium parasite is carried by the anopheles mosquito which breeds in bodies of fresh or brackish water. Once transferred to a human host by an infected mosquito, the parasites travel to the liver where they multiply and enter the bloodstream. The parasites continue to multiply in the red blood cells, which burst, and cause the characteristic symptoms of the disease. Fever, chills, headache, muscle aches, tiredness, nausea and vomiting, diarrhea, anemia, and jaundice begin to present themselves 10 days to 4 weeks after infection. Severe cases cause more symptoms and, if not treated promptly, can lead to cerebral forms and then to death [101].

Malaria affects an estimated 300-500 million people annually, causes more than one million deaths each year, and is one of the leading causes of under 5 mortality in Africa. Sub-Saharan Africa bears 90% of the disease burden with two thirds of the remaining burden concentrated in six countries: Brazil, Colombia, India, Solomon Islands, Sri Lanka and Viet Nam. Medications are available and control measures include early detection and treatment, preventative therapy, the use of insecticide treated bed nets, and environmental management [101]. On average, 42% of malaria cases in a given country could be eliminated with better habitat control [64].

B.2.9 Onchocerciasis (River Blindness)

Onchocerciasis is a water-related vector disease spread by biting blackflies which causes severe itching, skin depigmentation ("leopard skin"), lymphadenitis, elephantiasis of the genitals, serious visual impairment and blindness. It is the second leading cause of blindness due to infection, affecting more than 18 million people in more than 40 countries, most of which are in Africa [102].

The disease is spread when a person is bitten by a blackfly infected with the larvae of the Ochocerca volvulus worm. The worm larvae develop into adult worms inside their human host and settle into fibrous nodules near joints or the surface of the skin. The adult worms produce millions of microscopic microfilariae which migrate through the skin causing blindness upon reaching the eyes or a range of other symptoms throughout the body. The disease is proliferated when infected persons are again bitten by a blackfly and the disease is carried to another host. The spread of onchocerciasis can be controlled with breeding site management and drug treatment. The disease has been limited or eliminated in the Americas through mass drug administration and elimination programs have been established in Africa which aim to eliminate the disease there as well [102].

B.2.10 Schistosomiasis (Bilharzia or Snail Fever)

Schistosomiasis is a water-based disease that places approximately 600 million people at risk of infection, causing it to be the second most important parasitic infection behind malaria in terms of public health and economic impact. Symptoms begin with a rash or itchy skin and develop, over two months, into fever, chills, cough and muscle aches. Severe cases or repeated infections may lead to blood in the urine and feces, an enlarged liver or spleen, liver disease, kidney and bladder disease, seizures, paralysis, and spinal cord inflammation.

The infection cycle begins when the skin of people participating in activities that require water contact, such as laundry or water collection, become penetrated with cercariae larvae from one of three species of flatworm: Schistosoma haematobium, S. japonicum, or S. mansoni. The larvae enter the blood stream where they develop into schistosomulae and grow into worms in the liver, intestines, and bladder. Mature worms mate and produce thousands of eggs which cause damage to the bladder and liver as they work through the tissues, causing inflammation and disease. The eggs then exit the body through excrement into water where they hatch and form larvae called miracidiae. These larvae infect fresh water snails and transform into the cercariae larvae which are then released and ready to begin the cycle again [103], [104].

Schistosomiasis is endemic in 76 countries worldwide, the majority of which are in Africa. Approximately 80% of the transmission of the disease occurs there. Other affected regions include Brazil, Suriname, Venezuela, and several Caribbean islands in the Americas; Iran, Iraq, Saudi Arabia, Syrian Arab Republic and Yemen in the Middle East; and Cambodia, China, Indonesia, Japan, Laos and the Philippines in eastern Asia. The disease can be controlled with improved water and sanitation sources and with a single annual dose the drug Praziquantel, which costs about US 18 cents [103], [104].

B.2.11 Trachoma

Trachoma is a disease which affects the eyes. Repeated infections cause scarring on the inside of the eyelids and eventually the eyelashes turn inward and rub on the cornea leading to corneal damage, severe vision loss, and eventually blindness. Trachoma is highly contagious and is contracted through inadequate hygiene, human-to-human contact, or flies which carry the infected discharge from the eyes. Trachoma is especially prevalent among children, who spread the disease to other children and to their mothers. Many people are first infected as children and after repeated infection, are blinded by the disease as adults [64], [105].

Blinding trachoma occurs worldwide, most often in the poor rural communities of developing countries. The disease is widespread in the Middle East, Africa, parts of the Indian subcontinent, southeastern Asia, and China. It also occurs in parts of Latin America and among native Australians. An estimated 6 billion people are blinded by Trachoma and 150 million are in need of treatment. Trachoma can be prevented by facial cleanliness, access to safe water, adequate sanitation, and with fly control. Antibiotics have proven effective in treating eye infections and surgery can be performed to reverse the in-turning of lashes [64], [105].

B.2.12 Typhoid Fever

Typhoid and paratyphoid enteric fevers are water-borne bacterial infections of the intestinal tract and bloodstream caused by pathogens transferred from fecal contamination. Caused by Salmonella typhi and Salmonella paratyphi, these diseases are spread through ingestion of food or beverages either infected with the bacteria or contaminated by another person who has been infected. Flying insects may also contribute to the spread of the disease where contaminated feces is exposed. Once in the body, the bacteria begin to multiply and upon reaching the intestines pass into the blood stream. Symptoms include high fever, depression, anorexia, headache, bloody nose, constipation or diarrhea, red splotches on the chest, delirium, and inflammation of the liver or spleen, and usually occur 1-3 weeks after infection. Paratyphoid is generally a milder form of the disease which projects similar symptoms [106], [107].

The disease is prevalent in less industrialized countries where there are problems of unsafe drinking water, inadequate sewage disposal, and flooding. Typhoid is endemic in Central and South America, Africa, the Middle East, and southern Asia but is severe in Sub-Saharan Africa, south-west Asia, and the island nations of the Pacific. 16-33 million cases result in an estimated 216,000 deaths annually. Its incidence is highest among children and adolescents 5-19 years of age [106].

REFERENCES

[1] T. Schouten and P. Moriarty, *Community Water Community Management: From System to Service in Rural Areas*: Practical Action, 2003.

[2] United Nations, "Report of the United Nations Water Conference," in *United Nations Conference on Water*, Mar del Plata, 1977.

[3] World Health Organization, "Drinking-Water and Sanitation, 1981-1990: A Way to Health," World Health Organization, Genevea1981.

[4] "Declaration of Alma-Ata," in *International Conference on Primary Health Care*, Alma-Ata, USSR, 1978.

[5] M. Black, "Learning What Works: A 20 Year Retrospective View on International Water and Sanitation Cooperation, 1978-1998," UNDP-World Bank Water and Sanitation Programme, Washington D.C. 1998.

[6] C. L. Choguill*, et al.*, "Planning for Water and Sanitation " University of Sheffield Centre for Development Planning Studies and the Loughborough University of Technology Water, Engineering and Development Centre. , London1993.

[7] United Nations Development Program, "New Dehli Statement," in *Global Consultation on Safe Water and Sanitation*, New Dehli, 1990.

[8] "World Declaration on the Survival, Protection and Development of Children " in *World Summit for Children*, New York, 1990.

[9] United Nations, "Agenda 21," in *United Nations Conference on Environment and Development*, Rio de Janerio, 1992.

[10] United Nations Conference on Environment and Development, "The Dublin Statement on Water and Sustainable Development," in *International Conference on Water and the Environment*, Dublin, 1992.

[11] World Water Assessment Programme. (2006, July 19). *Milestones*. Available: http://www.unesco.org/water/wwap/milestones/index.shtml

[12] United Nations, "United Nations Millennium Declaration," in *United Nations General Assembly*, New York, 2000.

[13] World Water Council, "The World Water Vision: Making Water Everybody's Business," in *Second World Water Fourm*, The Hague, 2000.

[14] International Conference on Freshwater, "Ministerial Declaration," in *International Conference on Freshwater*, Bonn, 2001.

[15] United Nations, "Plan of Implementation," in *World Summit on Sustainable Development*, Johannesburg, 2002.

[16] United Nations, "The Millennium Development Goals Report: 2010," New York2010.

[17] World Health Organization and UNICEF, "Progress on Sanitation and Drinking Water: 2010 Update," WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation2010.

[18] S. Cairncross*, et al.*, "Hygiene, Sanitation, and Water: What Needs to Be Done?," *Plos Medicine,* vol. 7, 2010.

[19] World Health Organization and UNICEF, "Global Water Supply and Sanitation Assessment 2000 Report," WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation2000.

[20] Joint Monitoring Programme. (2010, July 21). *Definitions and Methods: Introduction*. Available: http://www.wssinfo.org/definitions/introduction.html

[21] G. Hutton, "Economic Evaluation and Priority Setting in Water and Sanitation Interventions," in *Water Qualtity: Guidelines, Standards and Health*, L. Fewtrell and J. Bartram, Eds., ed London: IWA Publishing, 2001.

[22] P. R. Hunter*, et al.*, "Water Supply and Health," *Plos Medicine,* vol. 7, Nov 2010.

[23] "World population prospects: 1998 revision," United Nations, Department of Economic and Social Affairs, Population Division, New York 1999.

[24] World Health Organization, "Guidelines for Drinking-water Quality: Third Edition, Incorporating the First and Second Addenda, Volume 1: Recommendations," WHO Press, Geneva2008.

[25] L. C. Rietveld*, et al.*, "A tool for technical assessment of rural water supply systems in South Africa," *Physics and Chemistry of the Earth,* vol. 34, pp. 43-49, 2009.

[26] M. A. Montgomery*, et al.*, "Increasing Functional Sustainability of Water and Sanitation Supplies in Rural Sub-Saharan Africa," *Environmental Engineering Science,* vol. 26, pp. 1017-1023, May 2009.

[27] G. Hutton and J. Bartram, "Global costs of attaining the Millennium Development Goal for water supply and sanitation," *Bulletin of the World Health Organization,* vol. 86, pp. 13-19, January 2008 2008.

[28] UNDP-WSP, "Getting Africa on Track to Meet MDGs on Water and Sanitation: A Status Overview of Sixteen African Countries," UNDP: Water and Sanitation Programme - Africa, Nairobi2006.

[29] S. Cairncross, "Sanitation in the developing world: current status and future solutions," *International Journal of Environmental Health Research,* vol. 13, pp. S123-S131, Jun 2003.

[30] P. A. Harvey and R. H. Reed, *Rural Water Supply in Africa: Building Blocks for Sustainability*. Loughborough: WEDC: Loughborough University, UK, 2004.

[31] M. W. Jenkins and S. Sugden, "Rethinking Sanitation: Lessons and Innovation for Sustainability and Success in the New Millennium " UNDP, New York2006.

[32] J. R. McConville and J. R. Mihelcic, "Adapting life-cycle thinking tools to evaluate project sustainability in international water and sanitation development work," *Environmental Engineering Science,* vol. 24, pp. 937-948, Sep 2007.

[33] M. D. Sobsey, "Managing Water in the Home: Accelerated Health Gains from Improved Water Supply," World Health Organization, Geneva2002.

[34] J. Bartram and S. Cairncross, "Hygiene, Sanitation, and Water: Forgotten Foundations of Health," *Plos Medicine,* vol. 7, 2010.

[35] J. Bartram, "Improving on haves and have-nots," *Nature,* vol. 452, pp. 283-284, Mar 2008.

[36] W. Cosgrove and F. Rijsberman, *World Water Vision: Making Water Everybody's Business*. London: Earthscan Publications Ltd, 2000.

[37] A. Jimenez and A. Perez-Foguet, "International Investments in the Water Sector," *International Journal of Water Resources Development,* vol. 25, pp. 1-14, 2009.

[38] Organisation for Economic Co-operation and Development, "Measuring Aid to Water Supply and Sanitation," 2009.

[39] World Health Organization, "Global Annual Assessment of Sanitation and Drinking Water 2010: Targeting resources for better results " 2010.

[40] Organisation for Economic Co-operation and Development. (2010, September 15). *Creditor Reporting System*. Available: http://stats.oecd.org/index.aspx

[41] M. A. Montgomery and M. Elimelech, "Water and sanitation in developing countries: Including health in the equation," *Environmental Science & Technology,* vol. 41, pp. 17-24, Jan 2007.

[42] C. Harris, "Private Participation in Infrastructure in Developing Countries: Trends, Impacts, and Policy Lessons," Washington D.C.2003.

[43] D. A. Franco and C. E. Williams, ""Airs, waters, places" and other Hippocratic writings: Inferences for control of foodborne and waterborne disease," *Journal of Environmental Health,* vol. 62, pp. 9-14, Jun 2000.

[44] G. Howard and J. Bartram, "Domestic Water Quantity, Service Level and Health," Geneva2003.

[45] World Health Organization, "Guidelines for safe drinking water quality: first addendum to third addition, Volume 1: Recommendations," WHO Press, Geneva2006.

[46] G. White*, et al.*, *Drawers of Water: Domestic Water Use in East Africa*. Chicago: University of Chicago Press, 1972.

[47] S. M. Kleiner, "Water: An essential but overlooked nutrient," *Journal of the American Dietetic Association,* vol. 99, pp. 200-206, Feb 1999.

[48] P. H. Gleick, "Basic water requirements for human activities: Meeting basic needs," *Water International,* vol. 21, pp. 83-92, Jun 1996.

[49] U.S. National Research Council, *Recommended Dietary Allowances, 10th Edition*. Washington, D.C.: National Academies Press, 1989.

[50] J. R. Mihelcic*, et al.*, *Field Guide to Environmental Engineering for Development Workers*: American Society of Civil Engineers, 2009.

[51] World Health Organization, "Guidelines for Drinking-Water Quality: Volume 1 - Recommendations, Second Edition ", Geneva1993.

[52] G. B. Bukenya and N. Nwokolo, "COMPOUND HYGIENE, PRESENCE OF STANDPIPE AND THE RISK OF CHILDHOOD DIARRHEA IN AN URBAN SETTLEMENT OF PAPUA-NEW-GUINEA," *International Journal of Epidemiology,* vol. 20, pp. 534-539, Jun 1991.

[53] A. C. Gorter*, et al.*, "WATER-SUPPLY, SANITATION AND DIARRHEAL DISEASE IN NICARAGUA - RESULTS FROM A CASE-CONTROL STUDY," *International Journal of Epidemiology,* vol. 20, pp. 527-533, Jun 1991.

[54] WELL, "Guidance Manual on Water Supply and Sanitation Programmes," Loughborough University, UK1998.

[55] S. A. Esrey*, et al.*, "INTERVENTIONS FOR THE CONTROL OF DIARRHEAL DISEASES AMONG YOUNG-CHILDREN - IMPROVING WATER-SUPPLIES AND EXCRETA DISPOSAL FACILITIES," *Bulletin of the World Health Organization,* vol. 63, pp. 757-772, 1985.

[56] S. A. Esrey*, et al.*, "EFFECTS OF IMPROVED WATER-SUPPLY AND SANITATION ON ASCARIASIS, DIARRHEA, DRACUNCULIASIS,

HOOKWORM INFECTION, SCHISTOSOMIASIS, AND TRACHOMA," *Bulletin of the World Health Organization,* vol. 69, pp. 609-621, 1991.

[57] L. Fewtrell*, et al.*, "Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis," *Lancet Infectious Diseases,* vol. 5, pp. 42-52, Jan 2005.

[58] T. Clasen*, et al.*, "Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis," *British Medical Journal,* vol. 334, pp. 782-785, Apr 2007.

[59] P. R. Hunter*, et al.*, "Estimating the impact on health of poor reliability of drinking water interventions in developing countries," *Science of the Total Environment,* vol. 407, pp. 2621-2624, Apr 2009.

[60] P. R. Hunter, *Waterborne Disease: Epidemiology and Ecology*. West Sussex, England: John Wiley & Sons Ltd, 1997.

[61] World Health Organization, "The Global Burden of Disease: 2004 Update," Geneva2008 2008.

[62] UN Water. March 29). *Statistics: Graphs & Maps - Drinking Water and Sanitation*. Available: http://www.unwater.org/statistics_san.html

[63] K. Toepfer, "Water and Sustainable Development," National Council for Science and the Environment, Washington D.C.January 29-30 2004.

[64] A. Prüss-Üstün*, et al.*, "Safer Water, Better Health: Costs, benefits and sustainability of interventions to protect and promote health," World Health Organization, Geneva2008.

[65] A. Prost and A. D. Négrel, "Water, Trachoma, and Conjunctivitis," 1989.

[66] R. L. Guerrant*, et al.*, "Updating the DALYs for diarrhoeal disease," *Trends in Parasitology,* vol. 18, pp. 191-193, May 2002.

[67] A. M. Tomkins*, et al.*, "WATER-SUPPLY AND NUTRITIONAL-STATUS IN RURAL NORTHERN NIGERIA," *Transactions of the Royal Society of Tropical Medicine and Hygiene,* vol. 72, pp. 239-243, 1978.

[68] P. A. Sanchez and M. S. Swaminathan, "Hunger in Africa: the link between unhealthy people and unhealthy soils," *Lancet,* vol. 365, pp. 442-444, Jan-Feb 2005.

[69] B. Mathew, "Ensuring Sustained Beneficial Outcomes for Water and Sanitation Programmes in the Developing World," IRC International Water and Sanitation Center, Delft2005.

[70] V. Kirogo*, et al.*, "The Role of Irrigation on Improvement of Nutritional Status of Young Children in Central Kenya," *African Journal of Food Agriculture Nutrition and Development,* vol. 7, 2007.

[71] S. Batterman*, et al.*, "Sustainable Control of Water-Related Infectious Diseases: A Review and Proposal for Interdisciplinary Health-Based Systems Research," *Environmental Health Perspectives,* vol. 117, pp. 1023-1032, Jul 2009.

[72] S. Gundry*, et al.*, "A systematic review of the health outcomes related to household water quality in developing countries," *Journal of Water and Health,* vol. 2, 2004.

[73] W. J. Van Zijl, "Studies on Diarrheal Diseases in Seven Countries," World Health Organization, Geneva1966.

[74] R. U. M. Lindskog and P. A. Lindskog, "BACTERIOLOGICAL CONTAMINATION OF WATER IN RURAL-AREAS - AN INTERVENTION STUDY FROM MALAWI," *Journal of Tropical Medicine and Hygiene,* vol. 91, pp. 1-7, Feb 1988.

[75] J. Wright*, et al.*, "Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use," *Tropical Medicine and International Health,* vol. 9, pp. 106-117, 2004.

[76] J. Vanderslice and J. Briscoe, "ALL COLIFORMS ARE NOT CREATED EQUAL - A COMPARISON OF THE EFFECTS OF WATER SOURCE AND IN-HOUSE WATER CONTAMINATION ON INFANTILE DIARRHEAL DISEASE," *Water Resources Research,* vol. 29, pp. 1983-1995, Jul 1993.

[77] R. G. Feachem*, et al.*, *Water, Health and Development: An Interdisciplinary Evaluation*. London: Tri-med books Ltd, 1978.

[78] A. F. Trevett*, et al.*, "The importance of domestic water quality management in the context of faecal–oral disease transmission," *Journal of Water and Health,* vol. 3, pp. 259-270, 2005.

[79] K. Nath*, et al.*, "Household water storage, handling and point-of-use treatment," International Scientific Forum on Home Hygiene2006.

[80] C. J. L. Murray and A. D. Lopez, "The World Health Report 2002: Reducing Risks, Promoting Healthy Life," World Health Organization, Geneva 2002.

[81] T. Clasen, "Scaling Up Household Water Treatment Among Low-Income Populations," World Health Organization, Geneva2009.

[82] D. S. Lantagne*, et al.*, "Household Water Treatment and Safe Storage Options in Developing Countries: A Review of Current Implementation Practices," in *Water Stories: Expanding Opportunities in Small-Scale Water and Sanitation Projects*,

M. Parker*, et al.*, Eds., ed Washington DC: Woodrow Wilson International Center for Scholars, 2007, pp. 17-38.

[83] E. D. Mintz*, et al.*, "Safe Water Treatment and Storage in the Home," *JAMA: The Journal of the American Medical Association,* vol. 273, pp. 948-953, March 22, 1995 1995.

[84] E. Mazengia*, et al.*, "Effective and culturally acceptable water storage in Zimbabwe: Maintaining the quality of water abstracted from upgraded family wells," *Journal of Environmental Health,* vol. 64, pp. 15-18, Apr 2002.

[85] E. F. Schumacher, *Small is Beautiful: A Study of Economics as if People Mattered*: Blond & Briggs, 1973.

[86] M. Simpson-Hebert*, et al.*, "Participatory Hygiene and Sanitation Transformation: A new approach to working with communities," World Health Organization1996.

[87] W. P. Schmidt and S. Cairncross, "Household Water Treatment in Poor Populations: Is There Enough Evidence for Scaling up Now?," *Environmental Science & Technology,* vol. 43, pp. 986-992, Feb 2009.

[88] D. Bradley, "Health Aspects of Water Supplies in Tropical Countries," in *Water, Wastes and Health in Hot Climates*, R. Feachem*, et al.*, Eds., ed New York: Wiley-Interscience, 1977.

[89] S. Cairncross and R. Feachem, *Environmental Health Engineering in the Tropics: An Introductory Text*, 2nd edition ed. New York: John Wiley & Sons, 1993.

[90] World Health Organization. (2001, February 10). *Water-related Diseases: Ascariasis*. Available: http://www.who.int/water_sanitation_health/diseases/ascariasis/en/

[91] World Health Organization. (2001, February 11). *Water-related Diseases: Dengue and Dengue Haemorrhagic Fever*. Available: http://www.who.int/water_sanitation_health/diseases/dengue/en/

[92] World Health Organization. (2001, February 10). *Water-related Diseases: Diarrhoea*. Available: http://www.who.int/water_sanitation_health/diseases/diarrhoea/en/

[93] World Health Organization. (2001, February 10). *Water-related Diseases: Guinea-Worm Disease (Dracunculiasis)*. Available: http://www.who.int/water_sanitation_health/diseases/guinea/en/

[94] The Carter Center. (2011, February 10). *Guinea Worm Facts*. Available: http://www.cartercenter.org/health/guinea_worm/mini_site/facts.html

[95] The Carter Center. (2009, February 10). *Guinea Worm Facts*. Available: http://www.cartercenter.org/health/guinea_worm/mini_site/facts.html

[96] World Health Organization. (2001, February 11). *Water-related Diseases: Hepatitis*. Available: http://www.who.int/water_sanitation_health/diseases/hepatitis/en/

[97] World Health Organization, "Hepatitis A," 2000.

[98] World Health Organization. (2001, February 11). *Water-related Diseases: Japanese Encephalitis*. Available: http://www.who.int/water_sanitation_health/diseases/encephalitis/en/

[99] The Carter Center. (2009, February 14). *Lymphatic Filariasis Elimination Program*. Available: http://www.cartercenter.org/health/lf/index.html

[100] World Health Organization. (2011, February 14). *Lymphatic Filariasis*. Available: http://www.who.int/mediacentre/factsheets/fs102/en/#

[101] World Health Organization. (2001, February 11). *Water-related Diseases: Malaria*. Available: http://www.who.int/water_sanitation_health/diseases/malaria/en/

[102] World Health Organization. (2001, February 10). *Water-related Diseases: Onchocerciasis*. Available: http://www.who.int/water_sanitation_health/diseases/oncho/en/

[103] The Carter Center. (2009, February 16). *Schistosomiasis Control Program*. Available: http://www.cartercenter.org/health/schistosomiasis/index.html

[104] World Health Organization. (2001, February 10). *Water-related Diseases: Schistosomiasis*. Available: http://www.who.int/water_sanitation_health/diseases/schisto/en/

[105] World Health Organization. (2001, February 10). *Water-related Diseases: Trachoma*. Available: http://www.who.int/water_sanitation_health/diseases/trachoma/en/

[106] (2011, March 22). *Typhoid Fever*. Available: http://en.wikipedia.org/wiki/Typhoid

[107] World Health Organization. (2001, February 11). *Water-related Diseases: Typhoid and paratyphoid enteric fevers*. Available: http://www.who.int/water_sanitation_health/diseases/typhoid/en/